VOLUME III NUMBER 3

THE PHYSICAL REVIEW

A JOURNAL OF EXPERIMENTAL AND THEORETICAL PHYSICS

CONDUCTED BY
EDWARD L. NICHOLS
ERNEST MERRITT, AND FREDERICK BEDELL

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PUBLISHED FOR CORNELL UNIVERSITY.

MACMILLAN AND COMPANY

NEW YORK LONDON

BERLIN: MAYER AND MUELLER

Vol. I No. 1 January, 1896

TERRESTRIAL MAGNETISM

An International Quarterly Journal

PUBLISHED UNDER THE AUSPICES OF

THE RYERSON PHYSICAL LABORATORY

A. A. MICHELSON, DIRECTOR

Edited by

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"Magnus magnes ipse est globus terrestris"

—GILBERT, "De Magnete."

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NOTICE

Terrestrial Magnetism will appear four times a year, viz., during the months of January, April, July, and October. A volume will consist of four numbers, embrace about 200 pages and begin with the January issue.

Communications relating to the subject matter of the Journal, as broadly defined and suggested by the title, are solicited. All languages that can be printed with Roman characters will be admitted. *One of the main languages, however, should be used whenever possible.* The manuscript must be legibly written, type-written when possible, *in Roman script* and on one side of the paper only. If drawings (such as are absolutely essential) accompany the article they should be drawn in India ink and neatly finished.

It is earnestly recommended that communications intended for publication, especially foreign, be sent by *registered* mail. When communications have been, or are to be, published also in other journals, this should be stated. Publications intended for review should be sent in duplicate, when possible.

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Announcement.

With the January, 1896, issue appears the first number of a Journal devoted exclusively to Terrestrial Magnetism, and its allied subjects such as Earth Currents, Auroras, Atmospheric Electricity, etc. No apology will be made for thus adding one more to the already over large list of scientific periodicals. Indeed, it is this very multiplicity, making it possible for articles on Terrestrial Magnetism to appear anywhere but specially nowhere, that has made the need of concentration keenly apparent to the lovers of the science.

Primarily, the aim of this Journal will be, to create a broader sympathy and to afford an easier communication between widely separated workers in a field that is day by day receiving greater recognition and whose possibilities have not yet been fathomed; secondarily, to increase the army of workers and of students.

Without doubt one of the chief wants of Terrestrial Magnetism to-day is a convenient channel for the timely and friendly interchange of ideas among the specialists in the science. *There is not a single journal, at present, that supplies this want.* The literature is in consequence scattered over many and miscellaneous periodicals, often well-nigh buried away in obscure publications or in such as are only accessible to a select few. In how far the Journal will fulfill its prime purpose will depend principally upon the co-workers in the science. Now that Terrestrial Magnetism has an organ of its own—and that an international one—it behooves them to do their utmost to make the Journal in every sense a success and thus to justify the important step Terrestrial Magnetism has taken.

It is also the firm belief that the Journal should make it a special object to *increase* the ranks of the devotees by enlisting the interests of all the men of science who can contribute, whether directly or indirectly, towards the advance of the subject, such as astronomers, geographers, geologists, meteorologists, particularly, however, physicists and mathematicians. Here is a field full of interesting and fascinating problems, both of an experimental and of a theoretical nature, which can form the basis of legitimate and fruitful investigations. It is the intention, therefore, to have recognized authorities review the progress made in the various phases of the subject and to point out the direction in which further research is desirable and essential.

The day has gone by for studying the phenomena of the magnetized needle chiefly by reason of their possible value to the mariner and the surveyor. The higher view, ushered in by Humboldt and Hansteen, but most fully recognized by Gauss, that Terrestrial Magnetism is a subject worthy of the profoundest physical and mathematical study, has taken firm root and is steadily, though slowly, making progress. It gave birth to the famous Magnetic Union headed by Gauss and Weber. The epoch-making results which were the direct and indirect outcome of this magnetic association were equally beneficial to Terrestrial Magnetism and to science in general. It taught the physicist, among other things, how to make absolute magnetic measurements, and soon revealed to the scientific world that the earth's magnetism is in sympathetic touch not alone with terrestrial but also with *cosmical* influences. Hence, gravitation is not the

only bond that binds us in friendly union with our sister planets and our parent sun. The magnetic needle thus has become a most promising instrument of research, not alone in terrestrial but also in cosmical physics. *No other mechanical means is so surely and so completely recording the physical history of terrestrial and cosmical changes as the self-registering magnetographs of our magnetic observatories, whereby the fitful tremors of the delicately suspended magnetic needle are being indelibly fixed on the sensitized sheet. "On that paper, as Maxwell eloquently expressed it, the never resting heart of the earth is now tracing in telegraphic symbols, which will one day be interpreted, a record of its pulsations and its flutterings, as well as of that slow but mighty working [the secular variation] which warns us that we must not suppose that the inner history of our planet is ended."* This extract suffices to give a hint as to the possibilities of geomagnetic investigations. In directing our eyes and energies skyward to unravel the phenomena of the starry firmament, let us not forget that the Earth, too, has its secrets and its mysteries that ought to be disclosed. Is it not *geophysical* observatories, *generously* equipped and endowed, that we especially need today?

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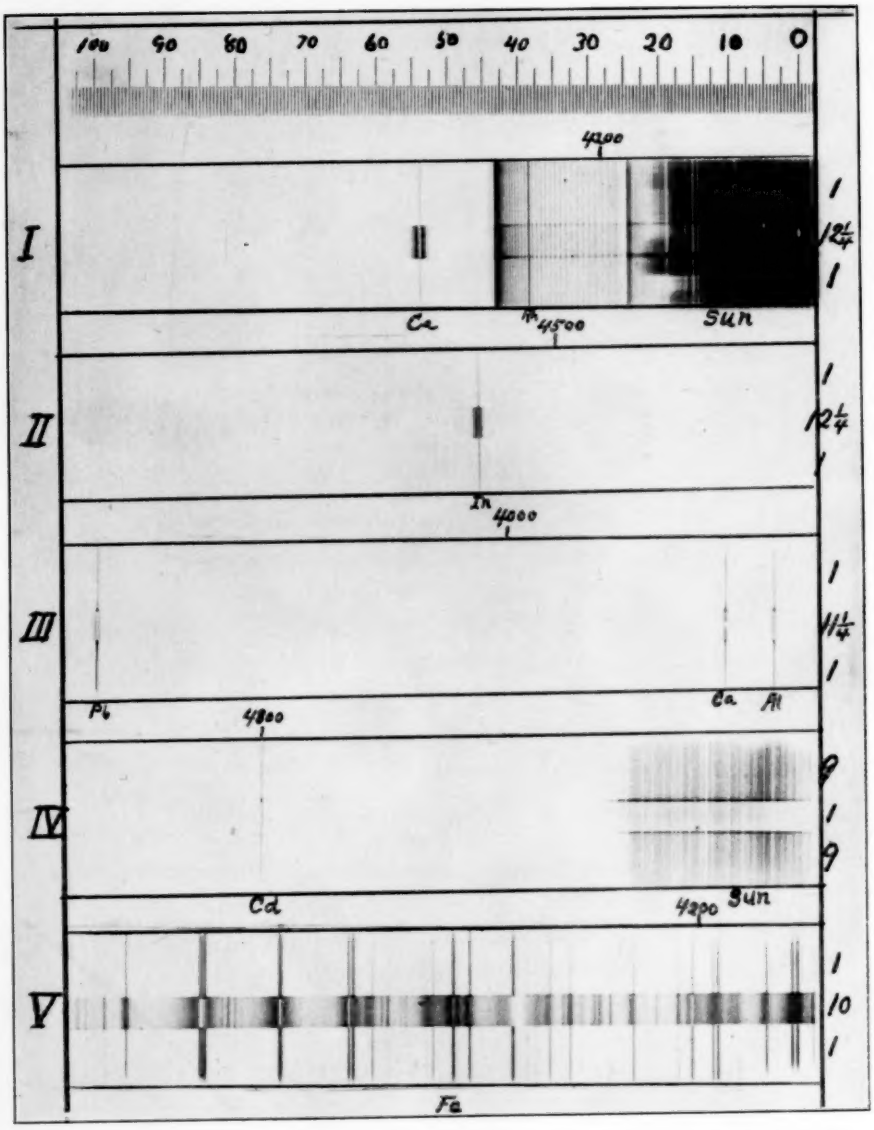
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THE
ASTROPHYSICAL JOURNAL

AN INTERNATIONAL REVIEW OF SPECTROSCOPY
AND ASTRONOMICAL PHYSICS

VOLUME III FEBRUARY 1896 NUMBER 2

THE COINCIDENCE OF SOLAR AND METALLIC LINES.

A STUDY OF THE APPEARANCE OF LINES IN THE SPECTRA OF THE ELECTRIC ARC AND THE SUN.

By L. E. JEWELL.

DURING the winter of 1890, while making the measurements upon which are based the values for the wave-lengths of the metallic lines in Professor Rowland's "New Table of Standard Wave-Lengths," I found that the metallic lines were almost invariably displaced toward the violet, when compared with the corresponding solar lines.

As Professor Rowland was not convinced that the displacement was due to any other cause than the accidental movement of the apparatus, when changing from the spectrum of the Sun to that of the arc, the displacement was treated as due to this cause, and the wave-lengths of all metallic lines corrected for the average displacement of the stronger "impurity lines" (generally iron) upon the plate, thus reducing them to an approximate agreement with the corresponding solar lines.

Knowing that the plates measured had been taken with the greatest care, I investigated the subject more carefully, and found that not only was the displacement nearly the same for the same

lines, taken upon different plates, but that there was a distinct difference in the displacement, not only for the lines of different elements, but also for the lines of different character belonging to the same element.

Realizing that any movement of the apparatus could not produce a difference in the displacement for different lines upon the same plate, an explanation was sought for in the difference in the condition of the substances in the arc and the solar atmosphere.

The explanation that first suggested itself was that perhaps the Fraunhofer lines were produced by the absorption of cool gases descending in the solar atmosphere. This would mean a falling velocity of from twenty to forty miles per minute continuously over the whole solar atmosphere. This is not excessive when compared with the velocity of matter sometimes seen in the vicinity of Sun-spots, but it must be remembered that those are isolated cases, confined to limited regions, are seldom witnessed, and then only for a short time, while if the displacement of the solar lines is due to falling matter, it must occur over the whole solar atmosphere, and be kept up continuously. Furthermore, a downrush necessarily means a corresponding uprush. If the uprush were likewise of cool absorbing gases the solar lines would be considerably widened, while if the uprush were of highly heated gases, as would most probably be the case, all the lines in the solar spectrum would be paired, a bright with a dark line. As neither appearance is found it follows that generally the velocity of the gases giving the Fraunhofer lines must be slight.

The only explanation possible seemed to be that the observed displacement must be due to a difference in the conditions of matter in the electric arc and in the solar atmosphere. Almost the only possible differences are those of pressure or density of material and temperature, or both.

When the matter was carefully looked into it was seen that the lines whose displacements were greatest were the strongest lines of the element considered, and also those lines which occur most commonly as impurities, because of the ease with which they are rendered visible with a small amount of material; fur-

thermore, these lines are also the ones most easily reversed in the arc. They correspond to the "long lines" of Lockyer. The lines which were least displaced, or which were in some cases displaced toward the red as compared with the corresponding solar lines, were those which were with difficulty reversed, and which required a large amount of material, or a high temperature, or both, to render them visible. These correspond to the "short lines" of Lockyer.

It was also found to be the case that, in general, the position of a line with but little material present in the arc was approximately the same as the position of the line when reversed, or in other words, produced by the absorption of the outside portions of the electric arc, when a greater amount of material was present in the arc. The density of the material where the line is produced in these two cases would be approximately the same, but there would probably be considerable difference in temperature. Generally it is only the "long lines" which can be thus compared, the "short lines" being rendered visible with more difficulty, and being much more difficult to reverse.

These two classes of lines, when visible at the same time, are produced in different portions of the arc, or rather, the bright "short lines" are produced in the central portions of the arc where the density of the material is great and the temperature high, while the reversals of the strong or "long lines" are produced at the outside of the arc where the density is much less and the temperature lower.

If both classes of lines are produced in the same part of the solar atmosphere under identical conditions, then the line in the spectrum of the arc which agrees most nearly in position with the corresponding solar line must be produced under conditions the most nearly similar. As the solar line agrees most nearly in wave-length with the line produced in the center of the arc where the temperature and density are high, it follows that we have a means of determining the pressure, or temperature, or both, of the solar atmosphere where the Fraunhofer lines are produced, if we can separate the effects of temperature and pressure.

When the metallic lines in the less refrangible portions of the spectrum were measured for the table of standards, the behavior of the lines under different conditions was noticed, and it was found that with an increase in the amount of material in the arc there was an increasing displacement of the line toward the red, unless the line became reversed, when all further progress in that direction ceased.

When Professor Michelson published his observations upon the multiplicity of the lines of certain substances, those lines were observed in the arc with a concave grating of 20,000 lines to the inch, and 21 feet 6 inches radius. My observations confirmed his as to the multiplicity of the lines in question, but led to the suspicion that the multiplicity was caused by a complicated series of reversals.[1] The shifting of all these lines with variation of the density of material in the arc was observed carefully, and found to be very great. Particular attention was paid to certain lines of cadmium which Professor Michelson had found to be of a simple character. His observations were confirmed. As the red cadmium line, although easily rendered visible with a small amount of material in the arc, was only reversed with difficulty it was specially studied; and it was found that if the micrometer wires were set upon it with very little cadmium in the arc, then as the amount was increased, the line almost bodily left the cross-hairs, always moving toward the red. As the line retained its symmetrical shape this could not be due to an unsymmetrical broadening produced by the shading of the line increasing chiefly on one side. Beside this, the change in position was altogether too great to admit of this explanation.

In his work Professor Michelson took three of the cadmium lines as standards and determined their wave-lengths with very great accuracy; but when his results are compared with the wave-lengths of the same lines in Professor Rowland's table, there is a difference of two-tenths of an Ångström unit. Professor Rowland is of the opinion that the difference is due to an error in the wave-length for the D_1 line taken as the standard of

[1] I expect to publish my results shortly.

his table. Probably this is true to a considerable extent; but the difference is in the direction that it should be according to the results given above. The wave-length should be less in a vacuum than in the electric arc at atmospheric pressure.

Considering the subject carefully there seemed no reason to doubt that the wave-length of a line depended, to a certain extent, upon the conditions under which the material producing the line was present in the electric arc, the vacuum tube, or the solar atmosphere; or in other words, the vibration period of an atom depends to some extent upon its environment. An increase of the density of the material, and presumably an increase of pressure, seemed to produce a damping effect upon the vibration period.

There was at the time no opportunity and no means at hand, of carrying out the investigation further, and I have had no opportunity of pursuing the matter further since then, though some measurements were made, and through the kindness of Dr. J. S. Ames, a synopsis of a paper embodying some of these results and ideas, was read at the Astrophysical Congress, at the Columbian Exposition at Chicago, in the summer of 1893.

Being closely engaged upon other investigations, and hoping for an opportunity to secure more material, the paper was not completed and published, though more material was gradually accumulated, with the intention of soon publishing my results. Recently, however, Messrs. J. F. Mohler and W. J. Humphreys of this University have, besides observing the behavior of lines with varying density of material in the arc, considerably extended the scope of the work by observing the behavior of lines with the arc under pressures of from a quarter to about fifteen atmospheres.[1]

In the accompanying table will be found the differences in the wave-length of solar and metallic lines for several substances which occur in the Sun. Many more lines were measured, but those lines which were found upon investigation to be due to nearly coincident lines of two or more substances in the Sun, or which in the spectrum of either the Sun or arc were so closely

[1] See page 114.

associated with other lines as to affect the measurements, were rejected. The first column gives the origin of the solar line, the second column the intensity and character of the solar line; the third the intensity and character of the metallic line; the fourth the wave-length of the solar line (taken from the table being published in the ASTROPHYSICAL JOURNAL); the fifth the wave-length of the metallic line; the sixth the displacement of the metallic with respect to the solar line; and the seventh column the number of measurements upon which the wave-length of the metallic line and the displacement are based.

In the columns for intensity and character, *S* means *shaded* and *R*, *reversed*. The wave-lengths of the metallic lines are the means of the different measurements. There are a number of discrepancies, as would be expected under the circumstances, because the measurements upon many of the plates were made for other purposes, and upon some of the plates the solar or metallic lines, or both, were not of an ideal character. None of the plates were made for this investigation, so that in some cases they were not well suited for this purpose. The displacement given was not determined from the difference in wave-length of the metallic and solar lines as given in the table, but from measurements of the position of the solar and metallic lines upon the same plate. In some cases the solar line was unsatisfactory for the purpose of measurement, and the differences of the wave-lengths between the metallic and solar lines taken from the table would be more accurate, but the general agreement shows that the values given are in general fairly accurate, when we take into consideration the difficulties of measurement, and that in some cases there may be other substances which help produce the solar line in addition to those known.

It will be observed that the stronger reversed lines are those whose displacement is greatest, and that there is a gradual decrease in the amount of displacement as the lines are weaker and more difficult to reverse. It will also be seen that there is considerable difference in the displacement for the lines of different elements. Generally, when there is much of the material

producing the lines investigated, the reversal of a line which is produced upon the outside of the arc, where the density is slight and the temperature comparatively low, agrees approximately with the position of the same line, not reversed, when there is but little material present, and as a consequence the line is produced in the center of the arc, where, although the density (of the material producing the line) may be slight, the temperature is high. There are exceptions, however, particularly in the case of the lines of aluminium, manganese, barium, and strontium, where the lines produced under the circumstances mentioned do not coincide. In all of these cases the reversed line has the lesser wave-length. Whether the nature of other material present in the arc affects the result remains to be investigated. An increase in the quantity of the material producing the line always displaces the line toward the red; an increase in the quantity of other material does not seem to change the position of the line to the same extent, and in some cases, if not in general, changes it very little, if any. There are some indications that the position of a line depends in a measure upon what other substance is present, but it cannot be safely asserted that such is the case without further investigation.

This seems to have a bearing upon the question of the effect of temperature in changing the wave-length. If the reversed line and the fine bright line produced under the conditions considered are identical in position, then a change of temperature can have no effect in changing the wave-length; but, if the fine bright line is displaced with respect to the reversed line, the wave-length of the line, and, consequently, the vibration period of the atom must depend upon the temperature, unless the presence of other matter in the arc accounts for the displacement.

An observation bearing upon this subject is the appearance of a line when reversed more than once. In these cases each reversal is displaced toward the violet with respect to the preceding one, while the outside or last reversal is the one which most nearly coincides with the fine bright line. This is shown in a large number of cases, a good illustration of which is that of

the magnesium line *b*, in the arc, a curve of the intensity of which is given in Fig. 6.

Additional evidence is given by several plates which were taken by Messrs. Mohler and Humphreys in which, upon the same plate, were one spectrum produced by using a weak electrical current, and another spectrum produced by a strong current. In some instances the quantity of material used was greatest with the weak current in order to produce lines having the same appearance in the two cases, as the stronger current would volatilize the material more rapidly, and, as a consequence, the density of the vapor would be about the same in both cases. Little, if any, displacement was observed upon these plates.

These several lines of investigation all lead to the conclusion that the wave-length is affected but little, if any, by change of temperature.

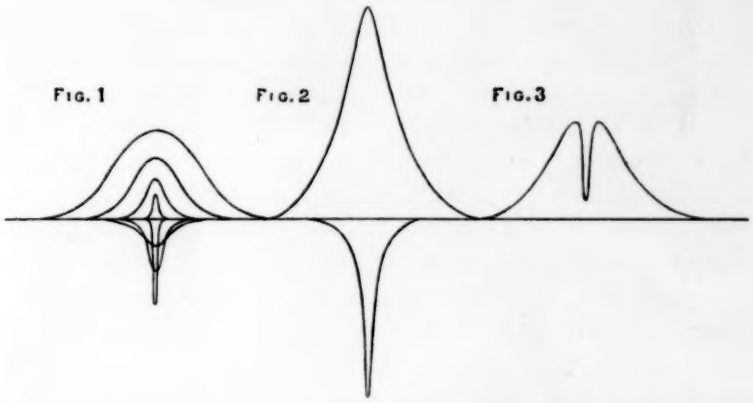
The reversals of the lines in the arc, as well as certain peculiarities in the apperance of some of the lines in the solar spectrum, when seen with the best definition, present many interesting peculiarities and some difficulties. As it is expected that this subject will receive further consideration at another time, I will only give some illustrations here.

A STUDY OF THE CHARACTERISTICS OF LINES PRODUCED BY THE ELECTRIC ARC.

Various considerations, as well as the appearance of lines in the spectra of the electric arc, show that taking the case of a line and the behavior in regard to it of different portions of the arc, we would obtain something like the following results.

The inner portion of the arc, where the temperature is high and the density greatest, would produce a broad bright line, brightest in the middle and gradually decreasing in intensity at the sides. There would be little if any trace of absorption, and, if any, it would be a broad line but of a very faint character. The outer envelopes of the arc, where the temperature is lower and the density least, would produce a comparatively faint and very narrow emission line, and an intense but very narrow

absorption line. The intermediate envelopes would give results intermediate between these extremes. In Fig. 1 the upper curves give a representation of the spectral appearance of an emission line as produced by envelopes at different distances from the center of the arc. The lower curves represent the corresponding absorption line. In Fig. 2 the upper curve represents the emission line produced by the combined effects of all of the envelopes and the lower curve the corresponding absorption line,



while Fig. 3 represents the reversed line which is a combination of these two effects. Both figures represent the typical cases generally seen in metallic spectra. From these considerations we may say that the width of a line depends upon the density of the material which produces it, and the pressure to which it is subjected. Whether the width depends directly or indirectly upon the temperature cannot be stated with certainty, though it is probably affected in both ways.

The intensity or brightness of a line of emission will depend upon the temperature of the material producing it, and the number of vibrating atoms from which the radiation is received.

The intensity or darkness of an absorption line will depend inversely upon the temperature, and directly upon the number of atoms whose sympathetic vibrations produce the absorption. (There are, however, limits to both effects.)

The character of a line produced in the electric arc will depend upon the distribution and density of matter in the envelopes from the center to the outside, and the relation of the radiating to the absorbing capacity of the matter composing these envelopes, and this will depend largely upon the distribution of temperature. The intensity curve of the line in Fig. 3 represents a typical case, but there are other cases which are widely different.

If there is a gradual change in the factors mentioned, from the center to the outside of the arc, we will have produced lines somewhat similar to those represented by Figs. 2 and 3; but, if there is not a gradual change in these factors, upon which the character of the line depends, and if the material of the arc is in a series of concentric layers, of maximum and minimum density, or if the change in the relation of the radiating to the absorbing capacity of the matter in the arc is not gradual from the center to the outside, but is variable in such a way as to give maxima and minima of intensity of radiation and absorption, we might have a series of multiple reversals such as is represented by the magnesium line in Fig. 6, and which is sometimes even more strikingly shown by the magnesium line at λ 2852.239 (one photograph shows four reversals of this line), and also readily shown by the sodium lines D_1 and D_2 in the arc.

A better explanation, differing somewhat from the above, is perhaps to consider the effect as produced by a large amount of material in the arc while the temperature is comparatively high, even near the outside of the arc. The central portions would give a very broad emission line, while the intensity of the absorption up to a certain distance from the center might be such as to prevent the transmission of any radiation whose period differed within certain limits from the fundamental or principal period. The absorption band produced would be, however, narrower than the emission line produced by the central portions of the arc. The radiation then produced by the matter from this layer to one somewhat further away, would give an emission line narrower than the absorption band given by the other layers nearer the

central portions of the arc, and the absorption of the layers further outside would produce a still narrower absorption line. The total or combined effect would be that of a multiple reversed line.

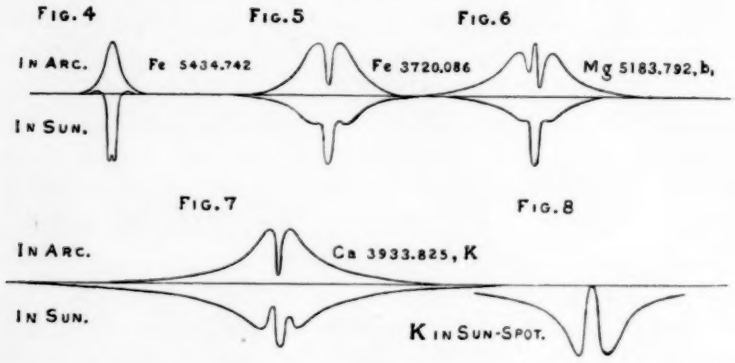
Taking into consideration the shift or change of wave-length with increasing density of material, or increasing pressure, the matter is somewhat further complicated. If the radiation from the denser portions of the arc constitute the principal source of the emission line, and particularly if the radiation corresponding to the middle of the line increases in intensity as the breadth of the line increases, the appearance of the emission line will remain symmetrical or nearly so, though where there is absorption on the outside, the reversal will be displaced toward the violet with respect to the center of the line. These are the ordinary types of lines.

However, if the intensity of radiation for the sides of the line increases more rapidly than the middle as the breadth of the line increases, and if the intensity of radiation corresponding to the middle portions of the line, falls off slowly from the center to the outside of the arc, an unsymmetrical emission line will be the result, or the line may be said to be unsymmetrically broadened. The question of temperature and temperature distribution in the arc probably largely controls this matter of the unsymmetrical broadening of lines. This is strongly indicated by some results that Messrs. Humphreys and Mohler obtained in their work; however, the whole question of the effect of temperature on the arc is in an unsatisfactory state.

CERTAIN PECULIARITIES IN THE APPEARANCE OF LINES IN THE SOLAR SPECTRUM, AND THEIR INTERPRETATION.

When the lines in the solar spectrum are examined carefully, in the light of the preceding considerations, some interesting facts are brought out. When some of the very best negatives of the solar spectrum are carefully examined, it is found that some of the sharp-edged, clean-cut, and unshaded lines of iron, chromium, manganese, titanium, etc., have a faint, dark shading just

outside the edge of the lines. It is very faint and difficult to observe (only slightly darker than the general background of the solar spectrum), but is not due to contrast, as it is not always present. It is a difficult observation to make, but was observed for some time before the explanation forced itself upon me. The correct explanation undoubtedly is that this faint, dark shading (dark in the negative) is the remains of an emission line, either produced at the photosphere or lower down in the



solar atmosphere than the absorption line. A good example is that of the iron line at λ 5434.742, an illustration of which is given in Fig. 4. (The lower curve is the solar line and the upper curve the metallic line.) The reason more good cases are not found, is that but few solar lines of this character are sufficiently isolated from fine lines, which mask the effect. Almost all lines of this character, however, show traces of this underlying emission line.

This emission line is rather broader than the absorption line (perhaps nearly two or three times as broad), and, consequently, is produced lower down in the solar atmosphere, where the pressure is much greater than in the strata giving us the absorption line. Another noticeable fact is the clean-cut, almost unshaded edges of these lines, showing that there is a considerable amount of gas (or a gas of intense absorbing power for radiations of this period), producing the absorption, which varies comparatively

little in pressure. In most of these lines whose width is sufficient to show the effect, there is a faint reversal showing matter at a somewhat lower pressure (consequently somewhat higher in the solar atmosphere), giving a faint emission line.

When the shaded lines are examined we find a different state of affairs. A good example is the iron line at λ 3720.086 and the magnesium line at λ 5183.792 (b_1). They are represented in Figs. 5 and 6.

Any trace of the primary emission line would be masked by the shading and would be too faint to be observed, but the most characteristic feature of these lines is the shading, which increases in intensity from the edges toward the central line. This is probably the first absorption line produced by the solar atmosphere. The gas producing this shading appears to have nothing like the same intensity of absorption for radiations of this wavelength as was found in the case of the other iron line, but is under a much greater range of pressure. When we consider the width of this shading and the width of the other line, and compare the result with the two corresponding iron lines in the spectrum of the arc, we are led to conclude that the gas producing the broader portion of this shading is situated at the same level in the solar atmosphere as the gas producing the other absorption line, but that the gas producing the whole of the shading extends through a much greater range of pressure and extends to a considerably higher altitude.

Examining the figures again we notice that there are traces of an emission line which must be produced at a higher altitude, as we see only the faint edges of this line (most of it being obliterated by the absorption of the central line). This emission line is not very noticeable. Inside this we find an intense, rather clean-cut, absorption line of nearly the same width as the other iron line, but slightly narrower, and not quite as sharp-edged as the other. This is the second and last absorption of this line. When we take into consideration the relative intensity of the two corresponding metallic lines, we find that this last absorption must be produced much higher up in the solar

atmosphere than the other line, where the pressure is very much less.

The appearance noticed is shown to a greater or less degree by all distinctly shaded lines in the solar spectrum. When the calcium lines H and K (Fig. 7) are examined the same state of affairs is shown, but to a much more remarkable degree. The primary emission line is of course invisible, but the extreme breadth of the shading, of both H and K, shows that the first absorption must persist through an extreme range of pressure, or that the amount of calcium gas varies enormously in the solar atmosphere where this absorption is produced. The second emission line of calcium is rather prominent in both H and K, but much more so in K, it sometimes being scarcely noticeable in the case of H.

The central absorption line is rather strong in both cases, but not so strong as in the shaded lines of iron, magnesium, and aluminium. This may be in part due to the background against which it is seen, but only in part, for the line has something of a diffuse appearance, similar to the lines of hydrogen, and unlike those of iron, etc. This central line is not much wider than the other lines considered, showing it to be produced by the absorption of calcium gas at a still greater elevation in the solar atmosphere.

An appearance that attracts attention is the unsymmetrical character of the central absorption line with respect to the emission line. This is more easily observed in the case of K than H, partly because the emission line is stronger, and partly, as we may say, it is less littered up with lines belonging to other elements, the neighborhood of the central line of K being almost free from other lines.

When different plates are examined, it is found that this dissymmetry varies upon different plates, to a considerable extent. Upon some plates the central absorption line is almost symmetrical with respect to the emission line, while upon other plates its unsymmetrical character is very marked, the central line being displaced considerably toward the red, and the part of

the emission line on the violet side of the central line being much the strongest.

The central absorption line also varies somewhat in width upon different plates, and the position of the maximum intensity for this central absorption line also varies from the middle of the line in some cases, to a considerable distance on either side in other cases. The emission line also varies somewhat in intensity and breadth.

A number of these plates have been measured and as a result it is found that the central absorption line varies in position to the extent of 0.025 of an Ångström unit, between the plates upon which the central line is symmetrically placed and the plates upon which it is most unsymmetrical. The displacement so far as has been observed, is always toward the red. In no case examined so far has the central line been perfectly symmetrical with respect to the emission line, or displaced toward the violet, and in no case has its wave-length been less, but always slightly greater than the corresponding metallic line. H gives the same results as K, but is more difficult to measure with accuracy.

An attempt was made to measure the position of the emission line in these cases. The measurements were too difficult to make to give any certain results, but there were some indications that the emission line might be slightly displaced toward the violet in the cases of dissymmetry. There are some indications, however, that these displacements in opposite directions of the absorption and emission lines are not compensatory, although probably connected with each other. The obvious explanation is that in the cases of dissymmetry we have examples of motion in the line of sight, the displacement of the central absorption line being due to falling matter, the extreme difference in velocity, shown by different plates, being about seventy-five miles per minute.

This downrush of matter is probably accompanied by an uprush from below corresponding to the emission line. Its velocity cannot be satisfactorily determined because of the

character of the line, and the interference of the absorption line. A velocity considerably less than that of the downrush is however indicated, although this may be accounted for by other considerations. The position of the central absorption line should be nearly the same as that of the corresponding fine reversal in the arc, providing there be no motion of either in the line of sight, as the matter producing both are probably at a comparatively low pressure and density. The emission line should, however, be displaced somewhat toward the red, as it is produced under greater pressure. Evidently this displacement due to pressure is overcome by the velocity of the uprush, as the emission line has nearly the same position as the metallic reversal. More than this I cannot say, as measurements are too difficult to be very accurate.

It is quite likely that the somewhat diffuse character of the central absorption line, and its lack of intensity when compared with the corresponding lines of iron, magnesium, and aluminium, may be the result of this motion in the line of sight, and this explanation is strengthened by the change in the position of maximum intensity noticed. Thus as a result of more or less variation in velocity, the line might be spread out considerably, whereas from the probable elevation and low pressure existing in that portion of the solar atmosphere where this central line is formed, we would expect to find a very narrow line, as the metallic reversals of H and K are generally narrow lines. (The curve in Fig. 7 represents the usual appearance of H and K in the spectrum of the arc, though the curve for b_1 in Fig. 6, — not the usual appearance of b_1 in the arc, but an exceptional case, — corresponds more nearly to the appearance of H and K in the solar spectrum.)

There are no dates upon the plates measured, which renders the matter uncertain, but there are indications that the plates showing the displacement were not taken at the same time as the others, possibly at a different part of the Sun-spot period. More or less dissymmetry seems to be the usual state of affairs, and symmetry the exception. This explains the extreme displace-

ment of the metallic with respect to the solar lines, in the cases of H and K. In Fig. 8 is given the appearance of H and K as observed in the spectrum of Sun-spots, with a large plane grating. The absorption of light of this wave-length, by the two large lenses of the spectroscope, was so great that the finer details were difficult to observe, but the bright reversals of H and K (emission-lines in this case) in the neighborhood of a spot were clearly visible, as well as the intense absorption in the shading near the reversal (the shading further away not seeming to be greatly affected). The absorption toward the red from the reversal was considerably darker and broader than toward the violet, thus giving evidence of considerable relative velocity between the emission line and the broad absorption line or shad ing. The narrow central absorption line was not observed.

The shaded lines of other elements have been examined, and their positions measured upon the same plates used in the determinations for H and K, with the following results. The strongest lines of iron show a displacement upon one set ot plates, with respect to another set, similar to that observed in the case of H and K, but to a much less extent. The extreme difference in velocity shown by the strongest iron lines is about twenty-five miles per minute, and a smaller velocity is shown by the lines of less strength. It is imperceptible in iron lines without considerable shading, and in the case of the weaker lines of iron there is no evidence whatever of any displacement or irregularity.

The aluminium lines show a difference in velocity of about fifteen miles per minute, while the shaded line of silicon at λ 3905.660, and the magnesium lines show no evidence of a change in velocity. Likewise there is no evidence of any variation in the carbon bands nor the weaker lines of any of the elements, one case being the faint calcium line at λ 3949.056, which shows no evidence of variation. As these measurements were confined to those plates containing H and K, the calcium line at 4226.904 (*g*) was not observed. Another interesting fact in this connection is the variation in the relative positions of the

absorption and emission lines of the strongest of the iron lines. Upon the plates that show H and K symmetrical, the emission line of iron shows quite distinctly upon the side of the absorption line toward the red (this is also shown distinctly in the case of the calcium line *g*, and is probably the effect of the greater pressure of those portions of the solar atmosphere where the emission line is produced). No trace of it can be seen upon the violet side. Upon the other plates the absorption and emission lines are symmetrically placed with regard to each other, or, in some cases, the emission line is most distinct upon the violet side. Some of these features are indicated in other shaded lines, but not at all distinctly.

Another observation of interest is the variable intensity of a line at λ 3719.801, which is situated in the shading of the strong iron line at λ 3720.082. It can be seen upon Professor Rowland's map of this region, and is quite distinct upon some plates, while not visible upon other plates showing lines closer to the iron line, and which are much weaker than the variable line upon the plates first mentioned. Other plates show this line between these extremes. A feature of the shaded lines to which attention should be called is the surprising weakness of this shading when we consider the great depth of the solar atmosphere when compared with the depth of what may be called the atmosphere surrounding the electric arc. The pressure indicated by the breadth of the shading must be very great at the lower depths of the solar atmosphere, but the comparative weakness of the shading would indicate comparatively little of the material producing the shading, or a feeble absorbing power. This weakness is rendered conspicuous when contrasted with the marked increase in the darkness of shading produced by a Sun-spot. It may be that vibrations easily produced at much lower temperatures are absorbed feebly by gases at much higher temperatures. The effect may also be accounted for by the eruptive nature of the photosphere, thus mingling the effects of an emission with an absorption line in the spectroscope, which may be unable to distinguish between the two with a small image of the Sun. If

the feeble absorption at high temperatures of radiations easily produced at lower temperatures, has anything to do with the appearance noted we may possibly account for the peculiar behavior of the calcium line *g*, which in the arc has the same appearance as H and K, but, unlike these lines in the Sun (which indicate the presence of enormous quantities of calcium in the solar atmosphere), the appearance of *g* would indicate the presence of comparatively little of the material producing this line.

Summarizing results, we may say that in some cases we can, in all probability, actually see through the cooler absorbing atmosphere of the Sun, and observe the original emission lines of the photosphere, or the gases immediately above it. Also, that while all the metallic lines in the solar spectrum are actually produced in those portions of the solar atmosphere close to the Sun's surface, the solar line, as we generally recognize it, may in some cases be produced at a considerably higher altitude. (In the case of H and K the central absorption line may possibly be produced by the corona.)

This effectually disposes of the necessity of any dissociation hypothesis to account for most solar phenomena.

Two adjacent lines of iron, for instance, may show the effects of a violent motion of iron vapor in opposite directions, in the neighborhood of spots, or one line (the smaller one-corresponding to one of Lockyers "short lines") may show a broadening and increase of intensity in the spectrum of a Sun-spot, while the other line (the larger one-corresponding to one of Lockyer's "long lines") is unaffected. But this does not prove that iron vapor is dissociated in the Sun. It merely shows that the apparently similar portions of the two lines in the solar spectrum are produced at different elevations in the solar atmosphere. The stronger iron line will be affected in a Sun-spot as much as the other one, but it is the portion of the line produced at the same level as the other line and may be masked completely or very largely, by the emission line produced at a higher level, while the second absoption line in the solar spectrum may be entirely unaffected, being produced at a still higher altitude.

This also explains why some of the lines (the short lines generally) of an element may be most prominent in Sun-spot spectra, while others (generally the long lines) are those most frequently seen in prominences or in the chromosphere.

Another fact bearing upon this question is that the shading of K (and to a less extent of H) is partially broken up into a series of faint nebulous lines, symmetrically situated about the central line. Some of these lines (which are absorption lines) are partially visible upon nearly all good plates of this region showing sufficiently good detail, but they are plainly visible upon only one plate (all of the lines upon this plate with the exception of the symmetrical series of H and K are visible upon the other plates and identical in their positions, relative intensities, etc.). The reason for this may be partially due to the comparatively weak character of the emission line upon this plate, thus unmasking these lines which are formed at a lower elevation, or it may be due to special conditions prevailing at the time the plate was taken. The slit of the spectroscope may have been over a group of Sun-spots, though the fact that the absorption shading of K (with the exception of these extra lines) is comparatively weak upon this plate, renders this explanation doubtful, though possibly the most probable one. That it is a series of calcium lines and connected with the shading of the K line is rendered certain by the symmetrical character of the series.

The strong shaded lines of iron also show this same kind of symmetrical series (though there are some differences). The best results are given by the iron line at λ 3720.086, which is probably the strongest line in the spectrum of iron and also the one freest from the contaminating influence of other lines. These faint series are visible upon all good plates in the third spectrum of a 20,000 grating of 21 feet 6 inches focal length, but are not visible with much distinctness in the second spectrum, the dispersion not being quite sufficient.

The shadings of other lines show some indications of breaking up into series, but will require greater dispersion to render the

DISPLACEMENT OF LINES.

	Intensity		Wave-length		Displacement	Number of Observations
	Sun	Arc	Sun	Arc		
Fe	3	3	3424.439	.444	+ 6	1
"	15 S	10 R	40.770	.761	− 9	1
"	12 S	10 R	41.163	.145	− 6	1
"	4	3	45.302	.308	+ 6	1
"	10 S	8 R	90.740	.722	− 7	1
"	6	5	97.991	.990	− 4	1
"	5	4	3536.706	.704	− 4	1
"	7	6	41.233	.240	+ 7	1
"	6	5	55.077	.072	− 6	1
"	40 S	30 R	81.352	.338	− 7	1
"	4	3	3617.935	.934	+ 10	1
"	18 S	15 R	18.931	.912	− 8	3
"	3	3	22.148	.155	+ 4	1
"	15 S	12 R	47.989	.983	− 13	2
"	4	3	49.655	.656	+ 3	2
"	10 S	8 R	87.610	.597	− 8	1
"	10 S	8 R	3705.710	.704	− 4	1
"	50 S	50 R	20.082	.075	− 11	2
"	4	4	24.526	.519	− 4	1
"	1	1	31.093	.084	− 6	1
"	40 S	40 R	35.014	.005	− 7	3
"	30 S	30 R	37.281	.270	− 12	3
"	4	3	38.454	.448	− 13	1
"	18 S	20 R	45.717	.691	− 9	1
"	15 S	18 R	46.058	.044	− 9	1
"	15 S	15 R	48.408	.406	+ 3	2
"	20 S	20 R	49.631	.628	− 6	3
"	2	2	57.081	.086	+ 2	1
"	18 S	18 R	58.375	.376	− 3	3
"	3	3	60.196	.198	− 1	1
"	3	2	60.679	.681	+ 1	1
"	12	12 R	63.945	.932	− 6	2
"	10	10 R	67.341	.336	− 7	2
"	2	2	74.971	.974	+ 2	1
"	8	8 R	88.046	.023	− 15	2
"	4	4	94.485	.481	− 6	1
"	10	8 R	95.147	.144	− 1	1
"	30 S	30 R	3815.987	.988	− 5	2
Fe, C	35 S	35 R	20.586	.568	− 10	5
Fe	10	10 R	24.591	.584	− 8	1
"	30 S	30 R	26.027	.025	− 7	5
"	15 S	15 R	27.980	.969	− 7	2
"	8	8 R	56.524	.515	− 6	2
Fe, C	30 S	25 R	60.055	.052	− 4	4

R means once reversed.
R¹ means doubly reversed.
N means nebulous.
S means shaded.

	Intensity		Wave-length		Displacement	Number of Observations
	Sun	Arc	Sun	Arc		
Fe	15 S	15 R	86.434	.415	— 13	18
"	8	8 R	3903.410	.398	— 9	1
"	10	10 R	28.075	.059	— 9	1
"	10	10 R	30.450	.438	— 7	1
"	4	4	37.479	.467	— 5	1
"	4	5	4022.018	.022	— 3	1
"	25 S	25 R	45.975	.964	— 12	7
"	5	5	62.599	.597	± 0	1
"	18 S	18 R	63.759	.751	— 7	7
"	3	4	67.429	.435	± 0	2
"	12 S	12 R	71.908	.898	— 9	7
Zr–Fe	4	4	4199.267	.263	— 3	1
Fe	6	8	4202.198	.194	— 6	1
"	3	3	22.382	.396	+ 14	1
"	6	8 R	71.934	.917	— 16	5
"	6	8 R	4308.081	.067	— 10	4
"	8	8 R	25.939	.921	— 12	4
"	2	2	52.908	.900	— 7	1
"	4	3	69.941	.937	— 4	1
"	4	4	76.107	.097	— 10	1
"	12 S	12 R	83.720	.705	— 15	7
"	10 S	10 R	4404.927	.911	— 16	6
"	7	8 R	15.293	.286	— 6	1
"	4	4	47.892	.886	— 6	1
"	4	4	94.738	.749	+ 11	1
Ni	12	18 R	3446.415	.398	— 14	1
"	3	4 R	67.647	.648	— 4	1
"	1	3	76.408	.414	+ 6	1
"	1	4	80.323	.311	— 8	1
"	0	1	88.444	.436	— 8	1
"	10	15 R	93.121	.087	— 14	1
"	1	1	96.498	.486	— 5	1
"	3	2	3507.837	.831	— 6	1
"	8	8 R	10.461	.468	— 3	1
"	10	18 R	15.201	.179	— 20	1
"	1	1	23.206	.209	— 6	1
"	15 S	20 R	24.671	.658	— 12	1
"	1	1	29.760	.760	— 5	1
"	5	5 R	48.328	.320	— 8	1
"	3	2	51.671	.668	— 5	1
"	1	1	60.060	.068	+ 6	1
"	0	0	77.383	.377	— 5	1
"	2	3	3602.430	.422	— 7	1
"	10	18 R	19.546	.520	— 25	1
"	5	6 R	3783.674	.664	— 10	1
Co	5	7 R	3395.530	.523	— 7	2
"	7	10 R	3405.263	.257	— 6	3
"	4	8 R	3998.053	.053	— 5	1

	Intensity		Wave-length		Displacement	Number of Observations
	Sun	Arc	Sun	Arc		
Co	1	3	4092.547	.546	− 9	1
"	4	8 R	4110.691	.690	− 2	1
"	4	8 R	18.934	.918	− 8	1
"	5	10 R	21.477	.475	− 5	1
Cr	7	30 R	4254.505	.490	− 11	2
"	d? 5	25 R	74.958	.958	− 5	2
"	4	20 R	89.885	.877	− 10	2
"	2	6 R	4337.725	.718	− 6	2
"	2	6 R	39.617	.608	− 6	2
"	1	3	39.882	.874	− 7	2
"	1	2	51.216	.214	− 4	2
Mn	9	30 R	4030.918	.900	− 14	11
Fe?-Mn	8	25 R	33.224	.213	− 12	11
Mn-Fe?	d? 7	20 R	34.644	.631	− 9	11
Co	5		35.752			
Mn	6	8 R	35.883	.881	± 0	3
Mn-Ti	d? 1	3	65.239	.220	− 20	1
Mn	2	5	70.431	.410	− 19	2
Mn,-	3	6	83.095	.072	− 25	2
Cu	9	40 R	3247.698	.672	− 22	2
"	d? 6	30 R	74.098	.093	− 9	2
Mg	15 S	25 R	3832.450	.440	− 9	1
"	20 S	35 R	38.435	.427	− 8	1
Al	15 S	40 R	3944.160	.151	− 5	26
"	20 S	50 R	61.674	.665	− 8	26
K	0	25 R	4044.294	.599	+ 2	3
"	00 Nd?	15 R	47.338	.571	+ 16	3
Si	10 S	10 R	3905.660	.661	− 6	15
C	d 0	3	3876.556			
	d 0	3	76.622	.580	− 8	11
Sr	8 S	40 R	4077.891	.866	− 16	6
Fe	2		4215.581			
Sr	4	45 R	15.703	.682	− 15	5
Sr	2	50 R	4607.510	.505	− 7	8
Ba	d? 7	45 R	4554.211	.204	− 10	2
"	d 3		4934.214			
	d 4	50 R	.277	.252	− 20	1

	Intensity		Wave-length		Displacement	Number of Observations
	Sun	Arc	Sun	Arc		
(K) Ca	100 S, R¹	100 R	3933.825	.794	− 23	26
Ca	1	3 N	3949.039	.056	+ 2	5
(H) Ca	80 S, R¹	90 R	68.625	.603	− 24	26
Fe	1		73.796			
Ca	3	6 N	.864	.864	± 0	5
(*g*) Ca	12 S	70 R	4226.904	.885	− 10	7
Ca	4	8 R	83.169	.162	− 8	6
"	3	8 R	89.525	.514	− 5	7
Ca, Mn?	3	8 R	99.149	.140	− 13	7
Ni ?, Ca	5	15 R	4302.692	.681	− 12	7
Ca	3	8 R	07.907	.894	− 10	6
Ti-Ca	4	10 R	18.817	.808	− 10	7
Ca,-	5	8 R	4425.608	.599	− 9	12
-, Ca	5	12 R	35.129	.123	− 6	12
Ca	4	8 R	35.851	.846	− 6	11
Zr?-Mn?, Ca	5	15 R	54.953	.941	− 10	10
Mn?-Ca	4	7 R	56.064	.056	− 4	3
Ca	3	2	5189.018	.010	− 8	1
"	0	0	5260.561	.549	− 4	1
Ca-Cr	3	2	61.876	.864	− 10	1
(E¹) Ca	4	4 R	70.438	.430	− 9	2
Fe	4		.558			
Ca	4	5 R	5582.198	.203	+ 7	4
"	6	12 R	88.985	.973	− 11	4
"	4	5 R	90.343	.347	+ 5	4
"	5	10 R	94.691	.683	− 6	4
"	5	8 R	98.711	.709	− 5	4
"	4	6 R	5601.505	.509	+ 4	4

series certainly visible. These series must be produced in the lower portions of the solar atmosphere, not far from the photosphere, where the temperature must be very high, and consequently it is evident that, whatever else may be said about it, iron and calcium atoms are not dissociated and broken up into simpler atoms, at the extreme temperature of the lower portions of the solar atmosphere.

The observations which I have considered have an important bearing upon many solar problems. By taking photographs either of opposite edges of the Sun, or still better in a manner similar to that of Professor Keeler in his work upon the rotation period of Saturn's system, it will be possible to deter-

mine the velocity of rotation for different heights in the solar atmosphere, by making a proper selection of lines for use, and taking the plates upon a large enough scale.

Another effect of this investigation may be to make the lines of the solar spectrum step down from the commanding position which they have occupied, as the standards of reference, for all work connected with the determination of the wave-length of any sources of light where extreme accuracy is required. In the case of the strong shaded lines we have proof that their positions are not the same upon different plates because of motion in the line of sight, and the amount of this motion evidently depends upon how high an elevation in the solar atmosphere the material producing an absorption line reaches. We also see that the wave-length of a solar line depends upon the depth in the solar atmosphere at which it is produced, and consequently upon the density and pressure at that level.

For nearly all practical purposes, however, the lines of the solar spectrum will answer perfectly well for standards of reference, if we exclude those lines which are produced at a considerable elevation. All other lines will probably retain a fixed position relatively to each other.

The lines of the electric arc will answer poorly where extreme accuracy in any future work is required, and it may be the duty of the vacuum tube to furnish our future exact standards, but it remains to be seen yet whether they will remain steadfast and true, or not. Professor Michelson's work would indicate that the lines thus produced are very constant in position.

In conclusion I should say that I am indebted for most of the material for this investigation of solar phenomena, to the series of beautiful negatives of the solar spectrum, which Professor Rowland made for his map of the normal solar spectrum. The grain of these plates is exceedingly fine and the definition almost perfect.

JOHNS HOPKINS UNIVERSITY,
Baltimore, Md., December 20, 1895.

EFFECT OF PRESSURE ON THE WAVE-LENGTHS OF LINES IN THE ARC-SPECTRA OF CERTAIN ELEMENTS.

By W. J. HUMPHREYS and J. F. MOHLER.

OBJECT AND METHOD.

THE purpose of the investigation described in this paper was to examine minutely the effects of pressure on the arc-spectra of the elements, and especially to note the effect, if any, on the wave-length. This idea was suggested by the fact that in the course of careful measurements of the arc and solar spectra made in this laboratory by Mr. L. E. Jewell, he detected certain discrepancies which showed a difference in the wave-lengths of the same line in the two spectra, and also that this difference varied with different elements.

A further reason for taking up this work was the fact that the wave-lengths of the red, green, and blue lines of the spark spectrum of cadmium vapor at low pressure as determined by Professor Michelson[1] for the purpose of accurately comparing them with the standard meter, are less than those of the same lines of the arc-spectrum at atmospheric pressure as determined by Professor Rowland;[2] the difference being .208 of an Ångström unit for the red, .173 for the green and .186 for the blue line. That their measurements, made in totally dissimilar ways, should differ by one part in thirty thousand is not surprising, especially since Professor Rowland's measurements are relative rather than absolute; but that there should be one difference for the red, and another for the green line, and that these should not be equal to each other by an amount too great to be considered an error of observation on the part of either or both of these skillful experimenters is remarkable, and it was hoped that the present investigation might explain, in some measure, this want of agreement.

[1] *Détermination expérimentale de la valeur du mètre en longueurs d'ondes lumineuses.*

[2] ROWLAND, *A. and A.*, 12, 1893.

On examining spectroscopic literature it was found that many observers had noticed the fact that increase of material broadened the lines. Some of the lines spread out symmetrically, others unsymmetrically, the increase in width being chiefly on the less refrangible side.[1] Similar results have been noticed when the source of light was under pressure. In both cases the width of a line probably depends in part at least upon the vapor pressure of the element that produces it, since, according to Schuster,[2] when gases are mixed in different proportions the lines of any one become sharper when it is present in smaller quantity, though the total pressure may remain the same.

Various theories have been proposed to explain the phenomenon of broadening of spectral lines, but nowhere have we found stated as a result of theoretical considerations or experiment that the wave-frequency itself may change and thus lead to a shift of the line as a whole. However, in speaking of absorption spectra, Kundt[3] says: "The position of the absorption band of a substance depends very essentially on the dispersion of the medium in which it is dissolved or incorporated. One often observes that in strongly dispersive media the absorption bands of a substance are displaced toward the red." It would appear from this that one might suspect the possibility of a similar phenomenon in the case of emission spectra.

In examining the effects of pressure on arc-spectra we used a twenty-one and a half foot concave Rowland grating of 20000 lines to the inch, mounted as described by Dr. Ames in the *Johns Hopkins Circular* of May, 1889. The arc was produced by a direct 110-volt current of any amperage desired, which, judging from the fuses blown, occasionally amounted to fifty or more. The pressures were always obtained by pumping air into a piece of apparatus designed by Professor Rowland several years ago and used by Messrs. Duncan, Rowland and Todd[4] in their examination of the electric arc under pressure. It consists, as shown

[1] KAYSER and RUNGE, *Abh. d. K. Akad. d. W. Berlin*, 1890–1.

[2] *Ency. Brit.* "Spectroscopy."

[3] KUNDT, Jubelband, *Pogg. Ann.* p. 620.

[4] *Electrical World*, **22**, 1893.

by Plate XI., of a cast-iron cylindrical vessel A, having at each end stuffing boxes B, B' through which pass insulated rods D, D' carrying carbons C, C'. The upper rod is regulated by a rack and pinion P, and the lower one by two screws S, S. The cylinder is prevented from becoming too hot by the water jacket K. A plane piece of quartz Q allows light from the arc to reach the spectroscope, and the window W enables one to know when the carbons are in proper position before turning on the current. The pressures were given by a gauge which could be read as often as desired, though it never changed appreciably after the current was on a few seconds.

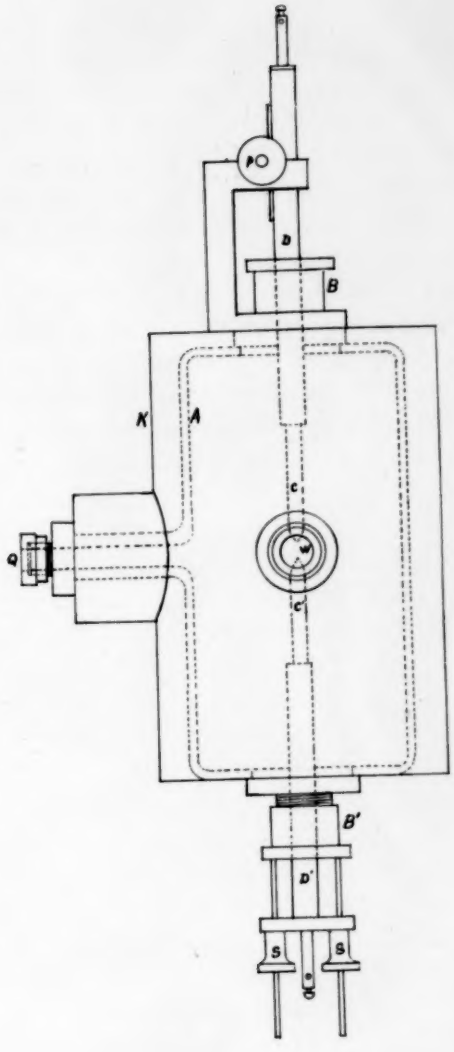
Nearly all the work was done in the second spectrum, the dispersion being a little more than one millimeter per Ångström unit.[1] Some observations were taken directly with a micrometer eyepiece, but most of the results were obtained from photographs which were measured on a dividing engine especially constructed for this sort of work, and used in determining Rowland's[2] table of standard wave-lengths.

The camera of the spectroscope, which takes a nineteen by one and a quarter-inch plate, is arranged for making two successive exposures, one on a narrow strip along the middle of the entire plate and the other on the remaining portions. In front of the camera were arranged shutters that enabled us to follow our usual method of photographing, which was to expose about an inch of the middle strip of the plate to the Sun, then the remainder of strip to the arc under pressure, then the corresponding outer portions to the arc at atmospheric pressure, and finally the remaining parts to the Sun. If plate or instrument had moved during the exposure the solar lines would thus have shown it. Besides, it was noticed that the lines of the carbon bands were never appreciably shifted and so these, some of which were found on nearly every plate, as well as the solar lines, enabled us to detect any disturbance of the apparatus during exposure. Unless stated to the contrary, a hole bored along the axis of the positive pole was filled with the material whose spectrum was to be examined.

[1] In all this work Rowland's scale is used.

[2] *A. and A.*, 12, 1893.

PLATE XI.



EXPERIMENTAL RESULTS.

Our first work was done with cadmium at atmospheric pressure. On varying the amount of material in the arc the width of the lines varied accordingly, and a large amount brought out clearly the reversals of the blue and green lines. The broadening was slightly unsymmetrical, being more towards the less refrangible portion of the spectrum, while the positions of the reversals coincided with those of the fine lines given by a small amount of material. Variation of strength of current did not appreciably affect the positions of the reversals of the lines of any substance examined, though the width of numerous lines increased, that of many of them unsymmetrically with increase of current. In the case of the aluminum lines at λ 3944 and λ 3961 the red side of the reversal was much stronger than the violet side. However, when pressure was applied to the arc containing cadmium, a decided shift in the positions of the lines was at once noticed. It was not simply unsymmetrical broadening, for it was possible to obtain fine sharp lines with and without pressure; nor was it a case of one line disappearing and another appearing in a slightly different position since it was often easy, while the pressure was being let off, to observe a line gradually change its position without alteration in width or other appearance. Such alterations, however, usually occurred unless special precautions were taken.

If, as is generally believed, the temperature of the arc is that of volatilizing carbon, it would be natural to suppose that it would rise with increasing pressure; but recent experiments by Wilson,[1] on the temperature of the arc under pressure, seem to show that it is lower at high pressures. In either case the shift might be due to change in temperature rather than pressure, and to test this point we used a long arc, perpendicular to the slit of the spectroscope; and with a heavy current exposed one part of a plate to the arc close to the positive pole and the other to the arc near the negative pole, as Wilson and Gray's[2] work indi-

[1] *Proc. R. Soc.* May 30, 1895.

[2] *Proc. R. Soc.* November 24, 1894.

cates that the temperature of the negative pole is much lower than that of the positive. We could detect no change in the position of the lines, but this of course does not settle the question as the temperature of the electric arc and how it varies from point to point is not known. Our work would indicate that the effect was that of pressure rather than temperature.

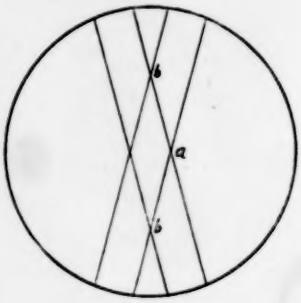


FIG. 1.

Over one hundred negatives were obtained; and the shifts of some lines—those whose positions were well defined—of twenty-three elements were measured in the following way: In the microscope of the dividing engine double cross-hairs were arranged in the manner shown in the figure, and the negative moved along by the screw until the cross a was on a given line of the middle strip when a reading was taken. The plate was then moved forward again by the micrometer screw until the crosses bb were on the same line, as photographed at different pressure on the outer portions of the plate, when another reading was taken, and so on for other lines. The plate was then reversed and the same process repeated. Let s be the shift of any line and l the difference in readings that would be given by the crosses a and bb when there is no shift, and let the direct reading of the crosses bb be λ, and the reversed d, then the direct reading of a will be $\lambda - l \pm s$ and the reversed $d - l \mp s$. Evidently $\lambda + d$ is a constant from which if the reversed readings be subtracted remainders will be obtained equal respectively to λ and $\lambda + l \pm s$. Consequently the average of the two read-

ings given by the crosses *b b* is λ and that of those given by the cross *a*, $\lambda \pm s$, their difference being the shift $\pm s$. By this method the accuracy of our measurements was about three thousandths of an Ångström unit.

The negatives showed that the general effect of pressure was to broaden the lines and to bring out the reversals. However this was not always the case, as it was possible to obtain with cadmium, for example, lines of about the same width with and without pressure; while in the case of some elements, as platinum and osmium, the lines were often narrower at high than at atmospheric pressure. The lines of the carbon bands were brought out more strongly by pressure, but, as already stated, they never showed much if any shift, which fact furnished conclusive evidence that the shift of other lines was not due to a disturbance of the apparatus, since they were all photographed simultaneously on the same plate, the lines of the carbon bands never being appreciably displaced while those of other elements were.

This displacement, or shift, varied greatly for different elements, but in the case of any one, with a single exception to be mentioned below, it was approximately proportional to the wave-length. The most conclusive evidence of this proportionality was furnished by lines of different orders of spectra that appeared on the same plate. Thus ultra-violet lines of the third order were often found on the same plate with the lines of the second of longer wave-length, but the measured shifts of the lines of the same element were approximately the same, and since the wave-length of a line of the third order is to that of one of the second that occurs at the same place as two to three, while the dispersion in the third order is to that in the second as three to two, it follows that constancy of measured shift means that it is proportional to wave-length. For the sake of comparison it was found advisable to reduce the shifts of all lines to what they would be at wave-length 4000, in the neighborhood of which most of our work was done. This reduction consisted of course in multiplying the measured shift of any line by the

ratio of 4000 to its wave-length. The exception referred to above is that of calcium. The lines H and K, among others, as shown by Table I., shift only about half as much as *g* and the group at wave-length 5600. That *g* should differ in this respect from H and K is not very surprising, since it is known to differ greatly from them in many other respects. According to Lockyer[1] it is the "longest line" of the calcium spectrum; that is, it occurs at the greatest range of temperature, even at that of an ordinary flame, while the H and K do not appear at temperatures much below that of the electric arc.

All our measurements showed that the shifts were invariably towards the less refrangible, *i. e.*, the red end of the spectrum, and that they were directly proportional, not only to the wave-lengths, but also to the excess of pressure above one atmosphere. It was found impossible, owing to the minuteness of the shift per atmosphere, and to the fact that our apparatus was not designed for vacuum work, to determine whether the same law holds for very low pressures. If it does, then about 8 per cent. of the differences between Professors Rowland and Michelson's determinations of the wave-lengths of the cadmium lines is accounted for. It is even possible that, as a vacuum is very nearly approached, the position of the lines may become much more sensitive to changes of pressure. Indeed, this is in a measure suggested by the results Schumann[2] obtained with the hydrogen line *Hβ*. This, of course, might account not only for 8 per cent. of, but, excepting minute and unavoidable errors, for the whole of the differences between Professors Rowland and Michelson's measurements.

It should be stated that in some cases the values obtained for the shifts may have been due in a measure to unsymmetrical broadening; but this has certainly not led to much error, since, as already stated, only those lines were used which could be accurately measured, that is, those which were either comparatively narrow or else reversed.

[1] *Chemistry of the Sun.*

[2] *A. and A.* **12**, 159, 1893.

TABLE I.

Element	Pressure	4¼	4¾	6	7	7½	8	9	9¼	9¾	10	10¼	10½	10¾	11	11¼	11½	11¾	12¼	12½	12¾	13	13½	14	14½
																29									
Fe	3997.547	..	..	..	..	..	..	..	..	..	..	..	..	..	..	29	..	..	..	..	..	..	..	..	..
					15						23				32										
"	4005.408	..	..	..	15	..	..	..	..	..	23	..	..	..	32	..	..	..	..	..	..	..	..	..	..
											18														
"	4009.864	..	..	..	..	..	..	..	..	..	18	..	..	..	..	..	..	..	..	..	..	..	..	..	..
			8	9												20									
"	4045.975	..	8	9	..	..	..	..	..	..	..	..	..	..	..	20	..	..	..	..	..	..	..	..	..
																23									
"	4063.759	..	..	..	..	..	..	..	..	..	..	..	..	..	..	23	..	..	..	..	..	..	..	..	..
											26														
"	4181.919	..	..	..	..	..	..	..	..	..	25	..	..	..	..	..	..	..	..	..	..	..	..	..	..
											25														
"	4199.267	..	..	..	..	..	..	..	..	..	24	..	..	..	..	..	..	..	..	..	..	..	..	..	..
											18														
"	4207.291	..	..	..	..	..	..	..	..	..	17	..	..	..	..	..	..	..	..	..	..	..	..	..	..
											18														
"	4219.516	..	..	..	..	..	..	..	..	..	17	..	..	..	..	..	..	..	..	..	..	..	..	..	..
			8		17								26		26										
"	4236.112	..	8	..	16	..	..	..	..	..	..	..	25	..	25	..	..	..	..	..	..	..	..	..	..
					11						26				31					35	25			34	
"	4250.945	..	..	..	11	..	..	..	..	..	25	..	..	..	29	..	..	..	..	33	24	..	..	32	..
			8	13	14										25	28	20		28	23	26			30	30
"	4271.934	..	8	12	13	..	..	..	..	..	..	..	..	..	23	26	19	..	26	22	24	..	..	28	28
											25														
"	4294.301	..	..	..	..	..	..	..	..	..	23	..	..	..	..	..	..	..	..	..	..	..	..	..	..
											26														
"	4298.195	..	..	..	..	..	..	..	..	..	24	..	..	..	..	..	..	..	..	..	..	..	..	..	..
																26			26		32	35		34	
"	4325.939	..	..	..	..	..	..	..	..	..	..	..	..	..	..	24	..	..	24	..	30	32	..	31	..

TABLE I.—*Continued.*

Element	Pressure	4¼	4¾	6	7	7½	8	9	9¼	9¾	10	10¼	10½	10¾	11	11¼	11½	11¾	12¼	12½	12¾	13	13½	14	14½
Fe	4377.948	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	21 19	..	..	..	..	..	..	..	..
"	4382.928	..	..	..	..	..	..	..	..	17 16	24 22	..	..	..	..	..	..	..	26 24	..	27 25	35 32	..	..	31 28
"	4383.720	..	..	..	..	..	..	..	..	17 16	..	..	..	..	..	..	28 26	..	..	..	..	..	..	..	..
"	4404.927	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	23 21	..	..	..	..	..	..	..	..
"	Average for iron	..	8 8	11 11	14 14	..	..	..	..	17 16	23 22	..	26 25	..	29 27	25 24	23 21	..	27 25	29 28	28 26	35 32	..	32 30	32 29
Ni	3391.180	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	14 17	..	..	..	..	..
"	3413.637	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	19 23	..	..	..	..	..
"	3414.092	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	19 23	..	..	..	..	..
"	3437.447	..	..	..	..	..	..	..	..	20 23	..	..	..	..	..	..	..	..	..	..	..	..	..	..	34 39
"	3458.606	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	27 31	..	..	..	..	29 33
"	3461.322	..	..	..	..	..	..	..	..	16 18	..	..	..	..	..	..	..	..	..	23 25	..	..	..	..	..
"	3500.993	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	24 27	..	..	..	..	35 40
"	3515.207	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	34 38	..	..	..	..	41 45
"	3524.677	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	30 35	..	..	..	..	..
"	5155.937	..	..	..	..	..	..	..	..	24 18	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..

TABLE I.—*Continued.*

Element	Pressure	4¼	4½	6	7	7½	8	9	9¼	9¾	10	10¼	10½	10¾	11	11¼	11½	11¾	12¼	12½	12¾	13	13½	14	14½
										20										24					35
Ni	Average for nickel.....	..	..	..	..	..	..	..	..	20	..	..	..	..	..	..	..	..	..	26	..	..	..	..	39
																				19					33
Co	3354.515	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	23	..	..	..	..	39
																				18					
"	3361.413	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	22	..	..	..	..	..
																				20					22
"	3395.016	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	24	..	..	..	..	26
										17															
"	3405.255	..	..	..	..	..	..	..	..	20	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
										14															23
"	3409.336	..	..	..	..	..	..	..	..	16	..	..	..	..	..	..	..	..	..	..	..	..	..	..	27
																				23					29
"	3417.384	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	27	..	..	..	..	34
										18															
"	3461.326	..	..	..	..	..	..	..	..	21	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
																20									
"	4121.476	..	..	..	..	..	..	..	..	..	..	..	..	..	..	19	..	..	..	..	..	..	..	..	..
										16						20				20					27
"	Average for cobalt.....	..	..	..	..	..	..	..	..	19	..	..	..	..	..	19	..	..	..	24	..	..	..	..	32
				13	12															32	27			37	
Mn	4018.269	..	..	13	12	..	..	..	..	..	..	..	..	..	..	..	..	..	..	32	27	..	..	37	..
			8												17										
"	4026.583	..	8	..	..	..	..	..	..	..	..	..	..	..	17	..	..	..	..	..	..	..	..	..	..
																19					33			34	
"	4030.947	..	..	..	..	..	..	..	..	..	..	..	..	..	..	19	..	..	..	..	33	..	..	34	..
			8	18	13																26			32	
"	4035.883	..	8	18	13	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	26	..	..	32	..
																20									
"	4061.881	..	..	..	..	..	..	..	..	..	..	..	..	..	..	20	..	..	..	..	..	..	..	..	..

TABLE I.—*Continued.*

Element	Pressure	4¼	4¾	6	7	7½	8	9	9¼	9¾	10	10¼	10½	10¾	11	11¼	11½	11¾	12¼	12½	12¾	13	13½	14	14½
			10		22																				
Mn	4235.298	..	10	..	21	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
			8		18								27		37						32			36	
"	4235.450	..	8	..	17	..	..	..	..	..	..	..	25	..	34	..	..	..	..	..	29	..	..	33	..
			13	21													31			48				47	
"	4239.890	..	12	20	..	..	..	..	..	:	..	..	..		..	..	29	..	..	45	..	..	..	44	..
			14	21	22								25		39						47			47	
"	4257.815	..	13	20	21	..	..	..	..	..	..	..	23	..	36	..	..	..	..	..	43	..	..	43	..
			14	20	22								38				40			41	40			46	
"	4266.081	..	13	19	21	..	..	..	..	..	..	..	35	..	..	..	37	..	..	38	37	..	..	43	..
			10		21								37		43		39			41	38			44	
"	4281.257	..	9	..	20	..	..	..	..	..	..	..	34	..	40	..	36	..	..	38	35	..	..	41	..
			12																						
"	4284.223	..	11	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
			11	19	19								32		34	20	37			40	35			40	
"	Average for manganese	..	10	18	18	..	..	..	..	..	..	..	30	..	32	20	34	..	..	38	33	..	..	38	..
			4												26									36	
Cr	3886.942	..	4	..	..	..	..	..	..	..	..	..	..	..	27	..	..	..	..	..	..	..	..	37	..
				16											20					12				29	
"	3919.309	..	..	16	..	..	..	..	..	.	..	..	..	..	20	..	..	..	..	12	..	..	..	30	..
			7												33									32	
"	3941.637	..	7	..	..	..	..	..	..	..	..	..	..	..	34	..	.	..	..	..	..	..	..	33	..
			7	12	16								23		27					36				47	
"	3963.831	..	7	12	16	..	..	..	..	..	.	..	23	..	27	..	..	..	..	36	..	..	..	47	..
			14	12	12					25					28									38	
"	3976.839	..	14	12	12	..	..	..	..	25	..	..	..	..	28	..	..	..	..	..	..	..	..	38	..
			12												34									49	
"	3984.059	..	12	..	..	..	..	..	..	..	..	..	..	..	34	..	..	..	..	..	..	..	..	49	..
					19																				
"	4026.318	..	..	..	19	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..

TABLE I.—*Continued.*

Element	Pressure	4¼	4¾	6	7	7½	8	9	9¼	9¾	10	10¼	10½	10¾	11	11¼	11½	11¾	12¼	12½	12¾	13	13½	14	14½
			3	9	19										26									26	30
Cr	4254.505	..	3	9	18	..	..	..	..	..	..	..	..	..	24	..	..	..	..	..	.	..	..	24	28
"	4266.894	..	..	..	..	..	..	..	..	..	17 16	..	..	..	..	..	..	..	..	..	..	..	..	..	..
"	4274.958	..	14 13	11 10	..	..	..	..	..	..	..	..	..	..	31 29	..	..	..	24 22	..	..	..	..	40 38	31 29
"	4280.556	..	..	..	..	..	..	..	..	..	..	..	..	..	30 28	..	23 22	..	..	..	..	..	..	..	..
"	4289.885	..	..	..	..	..	..	..	..	..	..	..	..	..	34 32	..	..	..	..	..	..	..	..	41 44	..
"	Average for cromium	.	9	14	16					25	17		23		29		23		24	24				38	31
		.	9	13	15	..	..	..	..	25	16	..	23	..	28	..	22	..	22	24	..	..	..	37	29
Pb	3639.728	..	.	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	63		
"	3683.622	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	70 70	..	..
"	4058.041	..	..	..	..	..	..	..	..	..	..	..	..	..	55 54	49 48	..	..	..	..	..	..	..	..	..
"	Average for lead	..	..	..	..	..	..	..	..	..	..	..	..	..	55 54	49 48	..	..	..	..	..	..	67	..	..
		..	..	..	..	..	..	..	..	..	..	..	..	..			..	..	..	..	..	..	73	..	..
Sn	3175.12	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	48 59	..	..	..	..	54 68
"	3262.44	..	..	..	..	..	..	..	..	37 46	..	..	..	..	..	..	..	..	..	47 58	..	44 55	..	..	51 63
"	3330.71	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	44 55	..	..	..	..	64 77
"	Average for tin	..	..	..	..	..	..	..	..	37 46	..	..	..	..	..	..	..	..	..	45 57	..	44 55	..	..	56 69
Bi	2898.08	..	..	..	..	..	..	..	..	..	26 35	..	..	..	..	..	..	..	..	..	..	..	..	..	..

TABLE I.—*Continued.*

Element	Pressure	4¼	4¾	6	7	7½	8	9	9¼	9¾	10	10¼	10½	10¾	11	11¼	11½	11¾	12¼	12½	12¾	13	13½	14	14½
											34														
Bi	2989.15	..	..	..	..	..	..	..	..	..	45	..	..	..	..	..	..	..	..	..	..	..	..	..	..
"	3397.31	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	48	..	..
"	Average for bismuth	..	..	..	..	..	..	..	..	..	30	..	..	..	..	..	..	..	..	..	..	..	48	..	..
										37	40											57	65	..	64
Tl	3519.342	..	..	..	..	..	..	..	..	41	..	..	..	..	..	..	..	..	..	..	..	..	73	..	72
																69									
In	4102.000	..	..	..	..	..	..	..	..	..	..	..	..	..	..	68	..	..	..	..	..	..	..	..	..
										73		81							102						125
"	4511.345	..	..	..	..	..	..	..	..	65	..	72	..	..	..	..	..	..	90	..	..	..	..	..	111
			17	29										44				49			48			67	
Al	3944.114	..	17	29	..	..	..	..	..	..	..	..	..	45	..	..	..	50	..	..	49	..	..	68	..
		17	25	26	37	36							44	40				57			52			76	
"	3961.674	17	25	26	37	36	..	..	..	..	..	..	45	41	..	..	..	58	..	..	53	..	..	77	..
		17	21	28	37	36							44	42				53			50			72	
"	Average for aluminium	17	21	28	37	36	..	..	..	..	..	..	45	43	..	..	..	54	..	..	51	..	..	73	..
																						16			
Pt	2830.41	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	22	..	..	..
																						14			
"	2893.98	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	20	..	..	..
																						12			
"	2897.99	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	17	..	..	..
																					12	17			
"	2929.91	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	16	24	..	..	..
																			15		17	18			13
"	2998.079	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	20	..	23	25	..	..	18
																						18			23
"	3042.745	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	25	..	..	32

TABLE I.—*Continued.*

Element	Pressure	4¼	4¾	6	7	7½	8	9	9¼	9¾	10	10¼	10½	10¾	11	11¼	11½	11¾	12¼	12½	12¾	13	13½	14	14½
																									16
Pt	3064.824	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	21
"	4442.723	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	25	..	..	31	..	..	..	
"	Average for platinum	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	23	..	..	28	..	..	..	..
Os	4260.993	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	20	..	15	18	..	..	..	18
"	4420.633	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	21	..	20	23	..	..	..	24
Rh	4211.6	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	17				
"	4375.0	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	16	..	..	..	..
Pd	3373.139	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	22	18				
"	3404.725	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	20	16	..	..	..	..
"	3421.367	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	45				
"	3433.578	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	43	..	..	..	..
"	3441.539	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	31		38	45				37
"	3460.884	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	28	..	34	41	..	..	..	34
"	3481.300	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	33			
"	3489.915	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	39	..	..	..
																							40		
																							47	..	..
																							38		
																							44	..	..
																							31		
																							36	..	..
																							31		
																							36	..	..
																							27		
																							31	..	..
																							25		
																							29	..	..
																							30		
																							34	..	..

TABLE I.—*Continued.*

Element	Pressure	4¼	4¾	6	7	7½	8	9	9¼	9¾	10	10¼	10½	10¾	11	11¼	11½	11¾	12¼	12½	12¾	13	13½	14	14½
Pd	3609.696	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	44	..	..
"	3634.841	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	48	..	..
"	3690.483	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	41	..	..
"	Average for palladium	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	45	..	..
Y	3950.497	..	5	7											15					17		14	28		
"	3982.742	..	5	7	..	..	..	..	..	..	..	..	..	..	15	..	..	..	..	17	..	14	31	..	..
Bo	2496.867	..	4		4															17		18	33		
"	2497.821	..	4	..	4	..	..	..	..	..	..	..	..	..	..	..	..	..	..	17	..	18	38	..	..
C	2478.661	..	..	..	..	..	19	23	25																
Cu	3247.680	..	..	..	..	..	30	37	40	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
"	3274.092	..	..	..	..	..	18	22																	
Ag	3280.80	..	..	..	..	..	30	35	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
"	3383.00	..	..	..	..	..		20	21																
Ca	3933.825 K	..	..	..	..	..	..	32	33	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
"	3968.625 H	..	..	..	..	..													25	28			28		
		..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	30	33	..	..	33	..	..
		..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	20	32		30	36		
		..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	25	38	..	36	41	..	..
										28										32					
		..	..	..	..	..	..	..	..	33	..	..	..	..	..	..	..	..	..	39	..	..	..	..	..
										34										27		32			
		..	..	..	..	..	..	..	..	40	..	..	..	..	..	..	..	..	..	32	..	38	..	..	..
		..	..	..	..	..	..	..	..	..	..	..	..	..	14	20	..	..	..	23	15				
		..	..	..	..	..	..	..	..	..	..	..	..	..	14	20	..	..	..	23	15	..	..	..	..
		..	..	..	..	..	..	..	..	..	..	22				30			33		17				
		..	..	..	..	..	..	..	..	..	..	22	..	..	..	30	..	..	33	..	17	..	..	..	..

TABLE I.—*Continued.*

Element	Pressure	4¼	4¾	6	7	7½	8	9	9¼	9¾	10	10¼	10½	10¾	11	11¼	11½	11¾	12¼	12½	12¾	13	13½	14	14½
				18											31						28				
Ca	4283.169	..	..	17	..	..	..	..	..	..	..	..	..	..	29	..	..	..	..	..	26	..	..	..	..
"	4289.525	..	..	17	..	..	..	..	..	..	..	..	..	..	21	..	..	..	..	..	40	..	..	..	..
"	4299.149	..	7	12	..	..	..	..	..	..	..	..	..	..	34	..	..	..	..	..	32	..	..	23	..
'	4302.692	..	..	11	..	..	..	..	..	..	..	..	..	..	26	..	..	..	..	..	28	..	..	23	23
"	Average for H and K group..	..	7	14	..	..	..	..	..	..	..	22	..	..	25	25	..	..	33	23	26	..	..	23	23
"	4226.904 g	..	..	..	..	..	..	..	..	..	..	..	..	..	..	46	..	..	48	..	..	53	..	..	82
"	5588.985	..	..	..	..	..	..	..	..	..	..	..	..	..	..	50	..	..	..	..	..	..	..	..	..
"	5594.691	..	..	..	..	..	..	..	..	..	..	..	..	..	..	52	..	..	..	..	..	..	..	..	..
"	5598.711	..	..	..	..	..	..	..	..	..	..	..	..	..	..	45	..	..	..	..	..	..	..	..	..
"	5603.083	..	..	..	..	56	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
"	Average for *g* group	..	..	..	..	40	..	..	..	..	..	..	..	..	..	48	..	..	48	..	..	53	..	..	82
Zn	4680.317	..	..	..	..	..	..	..	..	68	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
"	4722.342	..	..	..	..	..	..	..	..	52	..	..	..	..	..	..	..	..	49	..	..	..	53	53	..
"	4810.724	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	56	..	..	..	62	..	..
"	Average for zinc	..	..	..	..	..	..	..	..	55	..	..	..	..	..	..	..	..	53	..	..	..	58	..	..

TABLE I.—*Continued.*

Element	Pressure	4¼	4½	6	7	7½	8	9	9¼	9½	10	10¼	10½	10¾	11	11¼	11½	11¾	12	12¼	12½	12¾	13	13½	14	14½
Cd	4678.347	..	..	..	..	..	..	54	79	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
		..	..	..	..	..	..	46	67	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
"	4800.080	..	..	..	..	..	43	48	70	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
		..	..	..	..	..	36	40	58	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
"	5086.078	..	..	..	53	59	63	67	80	..	..	..	90	..	..	..	..	..	..	..	..	..	..	..	..	..
		..	..	..	42	46	50	52	63	..	..	..	71	..	..	..	..	..	..	..	..	..	..	..	..	..
	Average for cadmium	..	..	..	53	59	53	85	76	..	..	..	90	..	..	..	..	..	..	..	..	..	..	..	..	..
		..	..	..	42	46	43	69	63	..	..	..	71	..	..	..	..	..	..	..	..	..	..	..	..	..

DESCRIPTION OF TABLES AND CURVES.

Results of the measurements are given in Table I., in which the upper numbers in the line of each wave-length are the observed shifts in thousandths of an Ångström unit, and the lower their values when reduced to wave-length 4000. The curves (Plates XII. and XIII.), which are all plotted to the same scale from the averages of the table, have for abscissæ the reduced shifts, and for ordinates the pressures in atmospheres. The wave-lengths are taken, as far as possible, from Professor Rowland's table of solar wave-lengths, now in process of publication in the ASTROPHYSICAL JOURNAL. In some cases we used a former table of his published in *Astronomy and Astrophysics.*[1] The wave-lengths of osmium, palladium and platinum were taken from a table recently completed by Professor Rowland and Dr. Tatnall,[2] those of bismuth, tin and silver were obtained from a table by Kayser and Runge.[3]

Some idea of the character of the photographs may be obtained from the accompanying plate (Plate X.), at the top of which is a scale of wave-lengths divided into half Ångström units. I. and II. are portions of

[1] *A. and A.* **12**, 1893.
[2] *Ap. J.* October, 1895.
[3] *Abh. d. K. Akad. d. W. Berlin*, 1892–3.

PLATE XII.

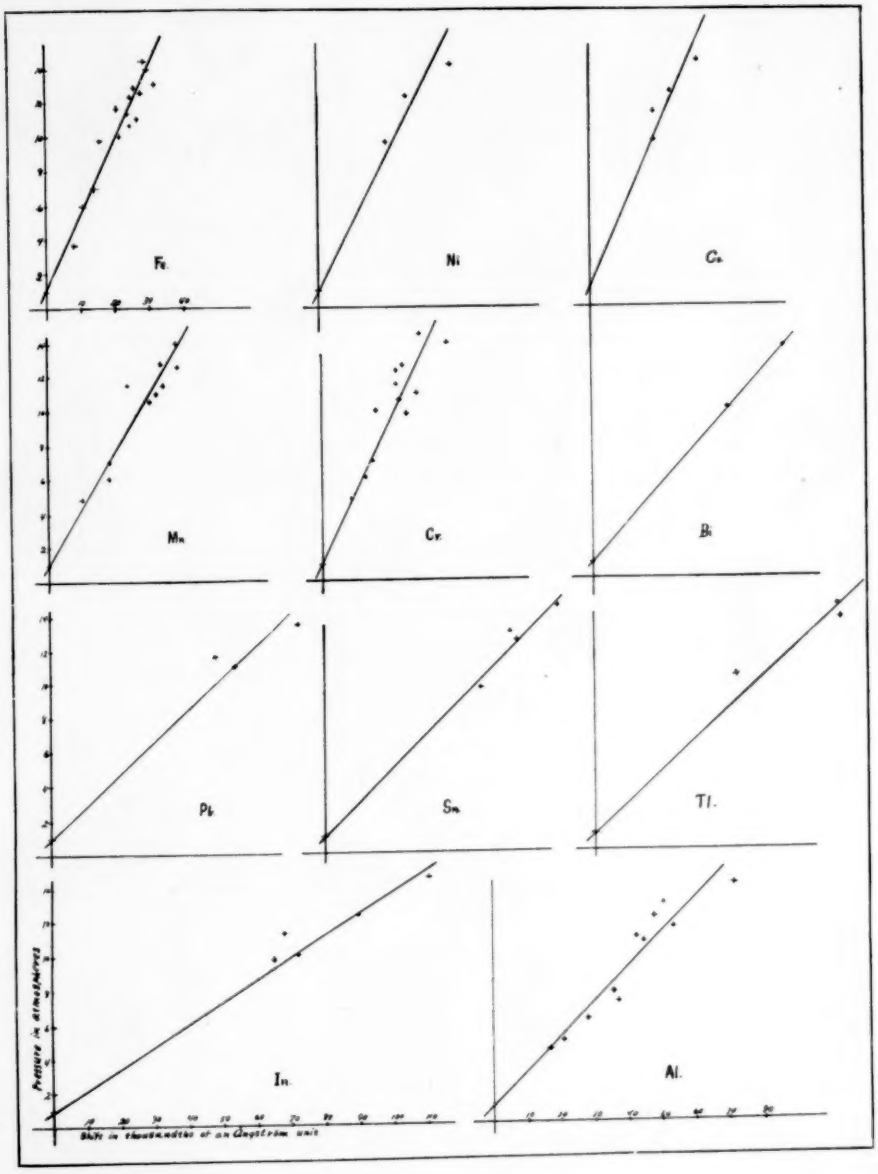
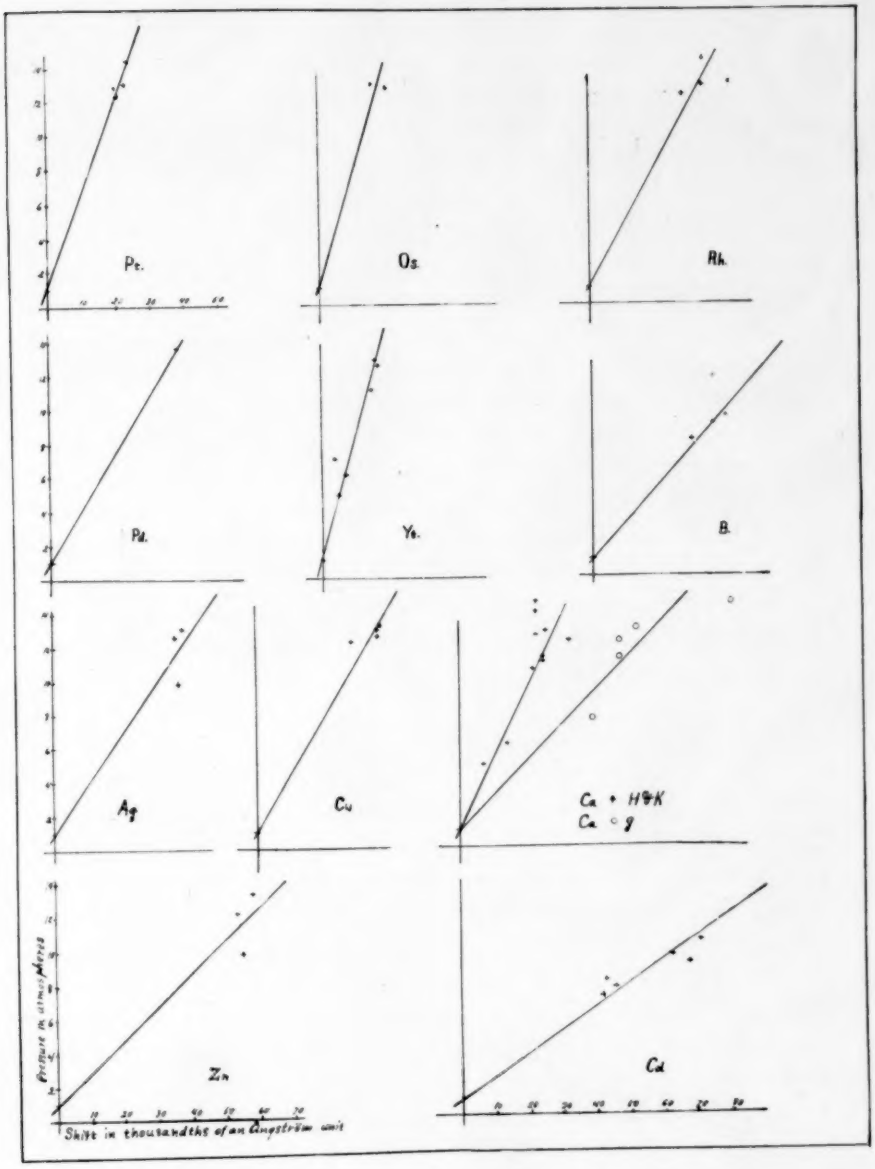

Fe.
Ni
Co.
Mn.
Cr.
Bi.
Pb.
Sn.
Tl.
In.
Al.
Pressure in atmospheres
Shift in thousandths of an Angström unit

PLATE XIII.


Pt.
Os.
Rh.
Pd.
Yt.
B.
Ag
Cu
Ca + H&K
Ca ○ g
Zn
Cd
Pressure in atmospheres
Shift in thousandths of an Ångström unit

the same negative, the pressures when the outer portions and middle strip were taken being respectively one and twelve and one-quarter atmospheres. I. shows the rhodium line of wave-length 4211, a portion of the solar spectrum, part of a carbon band and the calcium line *g*, while II. shows the indium line of wave-length 4511. III., the outer and middle portions of which were taken when the pressures were respectively one and eleven and one-quarter atmospheres, shows the aluminium line of wave-length 3961, the calcium line H and the lead line of wave-length 4058. IV. is from a negative showing the cadmium line of wave-length 4800, and a portion of the solar spectrum. In this case the middle strip was obtained when the arc was under a pressure of but one atmosphere, and the outer portions when the arc was under a pressure of nine atmospheres. V. is taken from a negative that was obtained when the arc was formed between a carbon negative and an iron positive pole, the pressures when the outer portions and middle strip were taken being respectively one and ten atmospheres. This photograph shows that, when the lines are close together, the effect of pressure is to form a practically continuous spectrum with only reversed lines, thus in a measure approaching the condition of the solar spectrum.

THEORETICAL RELATIONS.

In considering these numerical values of the shifts for different elements certain mathematical relations were discovered.

It was first noticed that forming for various elements the product of the cube root of the "atomic volume" and the coefficient of linear expansion of the substance in the solid form, certain numbers were obtained whose ratios were the same as those of the shift for the respective elements. The atomic volume is the ratio of the atomic weight to the density for any standard temperature; and its cube root was taken because the wave-length of any series of waves produced by a body varies directly as its linear dimensions. In our figures the atomic volume and the coefficient of expansion both refer to 40°C, and

the shift is that which corresponds to wave-length 4000. The agreement of the two sets of figures may be seen in Table II., fifth and sixth columns.

Raoul Pictet[1] has used a similar expression in his formula for deducing the melting points of the metals. He finds that the continued product of the absolute temperature of the melting point, the linear coefficient of expansion, and the cube root of the atomic volume is nearly the same for all the metals except bismuth.

The coefficient of expansion of a substance is, in a certain way, an inverse measure of the resistance of the atom to external forces; and without implying that shift is a direct temperature effect it is not unreasonable to suppose that the coefficient of expansion multiplied by a linear dimension of the atomic volume may be proportional to the change in the wave-length of the light emitted, since this product would be the actual change in the linear dimensions of the atomic volume, if there was any change in volume.

Table II. shows the connection of our work with that of M. Pictet, the eighth column giving the quotient of a constant, *i. e.*, 48600—divided by the absolute temperature of the melting point. The number 48600 was taken so as to reduce his results to numbers comparable with the shift at twelve atmospheres pressure, that for iron being made to coincide with the "theoretical value" $\alpha\sqrt[3]{V}$. This table shows that the shift is about as near the "theoretical value" as the melting point, and this would indicate that the product of the shift by the absolute temperature of the melting point is (with the exception of bismuth) nearly constant, or that the shift is inversely proportional to the absolute temperature of the melting point.

According to the above considerations the shift of the lines of mercury ought to be very large. We made a number of attempts to photograph the mercury lines but obtained no good results, as the lines, though showing a large displacement, were too hazy and diffuse to admit of accurate measurement. The

[1] *C. R.* **88**, 855, 1879.

work shows such close agreement between the shift and $\alpha\sqrt[3]{V}$ that the coefficient of expansion of the elements in the solid state at 40°C. may be calculated with some degree of probability if the atomic volume is known. On the above assumption the undetermined linear coefficients of expansion of the following elements would be:

For Manganese - -	.0000173
For Chromium - - -	.0000165
For Calcium (*g* line) - -	.0000184
For Boron - - - -	.0000309

In the case of calcium the calculation is based on the shift of the *g* line at wave-length 4226. The fact that the lines H and K have a different shift from *g* seems to agree with the theory that at very high temperatures some substances are dissociated.

TABLE II.

	W_1	V_1	α_2	$\alpha\sqrt[3]{V}$	S	T_1	$\frac{48600}{T}$	$\sqrt[3]{W}$
	.....	....	.0000	....	..	....	....	....
Fe	55.9	7.2	1210	23.3	25	2080	23.3	3.82
Ni	58.6	6.7	1279	24.	28	1870	26.5	3.80
Co	58.6	6.9	1236	23.6	24	2070	24.	3.88
Mn	54.8	6.9	....	....	33	2170	22.9	3.80
Cr	52.45	7.7	....	....	26	....	....	3.74
Bi	207.3	21.1	1621	44.7	49	538	90.3	5.92
Pb	206.4	18.1	2924	76.9	60	605	80.3	5.91
Sn	118.8	16.3	2234	58.4	55	503	96.6	4.92
Tl	203.7	17.2	3121	78.	61	563	86.3	5.89
In	113.6	15.3	4170	103.5	88	449	108.3	4.84
Al	27.04	10.6	2313	50.6	55	1123	43.3	3.00
Pt	194.3	9 1	0899	18.5	20	2050	23.7	5.79
Os	190.3	8.5	0657	13.4	17	2770	17.5	5.76
Rh	104.1	8.6	0850	17.4	30	2270	21.4	4.70
Pd	106.35	9.2	1176	24.7	33	1775	27.4	4.74
Y	88.9	....	....	....	15	....	....	4.46
B	10.9	4.	....	....	49	....	....	2.22
C	.....	....	0118	2.7	..	....	....	....
	11.97	3.6	0540	8.2	0	....	....	2.29
Ag	107.7	10.2	1921	42.2	38	1230	39.5	4.76
Cu	63.18	7 1	1678	32.5	33	1330	36.5	3.98
Ca	39.91	25.4	....	....	27	....	....	3.42
Ca	39.91	25.4	....	....	54	....	....	3.42
Zn	65.10	9.1	2918	61.2	57	676	71.9	4.02
Cd	111.7	12.9	3069	75.6	80	593	82.	4.82

[1] NERNST, *Theoretical Chemistry.*

[2] FIZEAU at 40°C. *Physikalish-Chem. Tabellen von Landolt und Börnstein.*

DESCRIPTION OF TABLE II.

The column marked W gives the atomic weights of the elements. Under V is given the atomic volume at 40°C., and under α the linear coefficient of expansion. In all cases this is from Fizeau's results at 40°C. The column marked $\alpha\sqrt[3]{V}$ gives the product of the linear coefficient of expansion by the cube root of the atomic volume multipled by 10^6. Under S is found the reduced shift at twelve atmospheres pressure. The column marked T gives the absolute temperature of the melting point and the next column marked $\frac{48600}{T}$ gives the quotient indicated. The last column gives the cube roots of the atomic weights.

Besides the relations already described a connection between the atomic weights and the shifts of the corresponding elements was also found. While this connection is not perfect, it nevertheless seems altogether too general to be merely accidental. The relation is as follows: Given the shifts of the lines of any element, the shifts of those of other elements belonging to the same Mendelejeff group, can be found on the supposition that they are to each other as the cube roots of the respective atomic weights. This is shown in the first part of Table III. in which the standard shifts, assumed to be correct, have all been determined by experiment and tabulated in Table II.

DESCRIPTION OF TABLE III.

Each horizontal row of Table III. shows the comparison between the observed shift of the lines of one element and that calculated for them from the observed shift of the lines of another element of the same group.

It will be observed that the calculated values agree almost exactly with the observed except in the case of boron, which, besides differing from the other elements in being non-metallic, furnished only two lines that could be measured, and even these were not very good.

Beyond the fact that atoms are exceedingly minute, scarcely anything is known of their actual size, nor is anything at all

TABLE III.

Showing shifts in thousandths of an Ångström unit for twelve atmospheres and wave-length 4000.

Standard		Calculated		Observed
Cu	33	Ag	39	38
Cd	80	Zn	66	57
Cd	80	Ca (*g*)	56	54
Al	55	In	89	88
Al	55	B	36	49
Sn	55	Pb	66	60
Co	24	Rh	29	30
Ni	28	Pd	34	33
Cd	80	Ca (H and K)	28	27
Al	55	Tl	54	61
Al	55	Y	41	15
Fe	25	Os	19	17
Ni	28	Pt	21	20

definitely known as to their density, and therefore, for all we know, the atoms of the same group may have either the same or different densities. If, however, they have the same density then (unless they differ in shape) their linear dimensions are to each other as the cube roots of their atomic weights; and consequently our measurements would mean that the shifts of elements of the same group have the same relations to each other as the linear dimensions of their atoms. Or, on the other hand, if it be accepted that the shifts are directly proportioned to the linear dimensions of the vibrating particles, then it would follow that the atomic density is constant for the elements of any group.

The lines of a few elements, yttrium, osmium, platinum, thallium and calcium (H and K) do not give shifts which at first seem to agree with this rule. If, however, we assume that these substances dissociate in the arc into eight equal parts (possibly dividing along three intersecting symmetrical planes and thus for many configurations giving the same shape to the parts as that of the original) then their observed shifts and those calculated using one-eighth of the atomic weights agree within experimental errors, except in the case of yttrium. This is shown

by the second part of Table III. Of course, if yttrium were assumed to dissociate a second time, in the way explained above, its calculated shift would be about twenty, which is within experimental error of its observed shift fifteen, but, as the yttrium earths still present puzzling difficulties, it does not seem worth while to offer regarding their lines any speculations, which possibly have already gone too far in regard to the behavior of other lines.

While the shifts of the lines due to elements of different groups (group used in the same sense that it is in the Mendelejeff periodic law) differ from each other greatly, it is nevertheless possible, in most cases, at least, to pass from one group to another by means of the ratios of the coefficients of expansion of elements of different groups but of the same series. Thus within experimental errors the ratio of the coefficients of expansion of copper to zinc, of silver to indium and tin, of cadmium to indium and tin, and of aluminium to iron, nickel and cobalt, is in every case equal to the corresponding ratio of shifts.

Bismuth, chromium and manganese are not put in Table III. because they are the only substances of their respective groups examined, and thus there is nothing with which to compare them.

Several unsuccessful attempts were made to photograph the ultra-violet lines of magnesium under pressure, in hope of obtaining the shifts of lines of the different series which occur at about wave-length 2750. We failed because the fumes generated by the arc absorbed the light, for in all cases the ultra-violet light is more absorbed than that of longer wave-length. In almost all our work we were limited to short exposures from this cause.

As noted above the lines of the carbon bands showed no appreciable shift with the pressures employed. Indeed in some cases they were used as "base lines" from which the shift of other lines was obtained. The single carbon line at wave-length 2478 is an exception as its shift as measured on several plates is about 0.046 of an Ångström unit at twelve atmospheres pres-

sure. In Table II. the values of α in the case of carbon are those given for diamond at 40°C and also for gas carbon, the upper number being for diamond and the lower for gas carbon.

Work was begun on this investigation in February 1895, and a preliminary paper on it was read at the Springfield meeting of the American Association for the Advancement of Science in September of this year.

Our work was done under the supervision of the directors of the Physical Laboratory, Professor Rowland and Dr. Ames. We would especially acknowledge our indebtedness to Dr. Ames for his assistance, as many of the points brought out are the direct results of his suggestions. Our thanks are also due to Mr. Jewell for assistance in the choice and measurement of the lines, and to Dr. Tatnall for kindly sending us his measurements of the palladium lines which are not yet published.

JOHNS HOPKINS UNIVERSITY

December 12, 1895.

NOTE ON THE PRESSURE OF THE "REVERSING LAYER" OF THE SOLAR ATMOSPHERE.

By L. E. JEWELL, J. F. MOHLER and W. J. HUMPHREYS.

THE investigation of the effect of pressure on the wave-lengths of the lines of arc-spectra,[1] together with the observation that many lines of the solar spectrum do not quite coincide with the corresponding lines of arc-spectra at atmospheric pressure,[2] seems to furnish a method of determining the pressures of the solar atmosphere where the Fraunhofer lines are produced.

The difference between the wave-lengths of the lines of ordinary arc-spectra and those of the Sun is most marked in the case of those that are strong in the solar spectrum, and at the same time strongly reversed in the arc. Most of the lines mentioned below are of this character.

Assuming that the solar atmosphere is comparatively quiescent, and that the displacements of the lines in the solar spectrum, referred to the arc at atmospheric pressure, and their shifts in the arc at different pressures (referred to the same standard) are both due to pressure alone, we find, on comparing these displacements and shifts, the results shown in the table on opposite page.

It will be noticed that two pressures, corresponding to two groups of lines, are given for the reversing layer of calcium. This comes from the difference in the shifts of these lines in the spectrum of the arc under pressure; but, excepting the lines H, K, and *g*, the two groups present the same appearance in the solar spectrum.

The lines H and K are peculiar in many respects, and are often displaced much more than any other calcium lines. Their positions, however, relative to other solar lines are found to be

[1] See page 114.

[2] See page 89.

Element	Wave-length	Pressure (in Atmospheres) of Reversing Layer
Al	3944.160	2
"	3961.674	
Si	3905.660	4
Ca	4283.169	6
"	4289.525	
"	4299.149	
"	4302.692	
"	4226.904	3
"	5588.985	
"	5594.691	
"	5598.711	
Cr	Several lines	5
Mn	" "	6
Fe	" "	7
Ni	" "	7
Cu	" "	7
Co	" "	4

different on different plates, and this difference in position is connected with certain peculiarities in appearance. Besides they occur in the chromosphere and always in prominences, where the pressure must be comparatively small. The narrowness of the central line in both H and K likewise indicates a comparatively low pressure for their final absorption. These facts, especially the difference in the positions of H and K on different plates, and their occurrence at great altitudes, make it appear probable that their displacements may be accounted for, at least in part, by motion in the line of sight. Their general appearance seems to indicate an enormous amount of material present throughout a great range of elevation and pressure, while the appearance of *g* indicates only a small amount of material with a limited range of elevation and pressure. The peculiarities of these lines are very marked, the causes of which are by no means perfectly understood, consequently a further discussion of them would be out of place in the present note.

These observations, as may be seen from the table, seem to indicate that possibly the upper limits of the reversing layers of the different elements in the solar atmosphere are arranged somewhat in the order of their atomic weights, those of heavier

atomic weights being at greater pressures, and consequently smaller elevations. This does not mean that these elements are not present at greater depths in the Sun, but that they do not occur to an appreciable extent at higher elevations where the pressure is less than that given by the method of comparison explained in this note.

PHYSICAL LABORATORY, JOHNS HOPKINS UNIVERSITY,
December 23, 1895

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PRELIMINARY TABLE OF SOLAR SPECTRUM WAVE-LENGTHS. XI.

By HENRY A. ROWLAND.

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
5914.118		0000	5922.578	A (wv)	0
5914.335 s	Fe	4	5922.735	A (wv)	2
5914.430 s	–, A (wv)	6	5922.930	A (wv)	0
5914.700	A?	0000	5923.235		0000
5914.850		0000	5923.405	A (wv)	00
5915.146	A (wv)	1	5923.500		0000
5915.380		0000	5923.702		0000
5915.650	A (wv)	1	5923.865	A (wv)	1
5915.840	A (wv)	1	5924.040	A (wv)	2
5916.050	A (wv)	000	5924.180		000
5916.240	A (wv)	00	5924.490	A (wv)	4
5916.475 s	Fe	3	5024.787		0000
5916.675		0000	5924.975	A (wv)	000
5916.800	A (wv)	0	5925.082		0000
5916.984	A (wv),–	000	5925.220	A (wv)	2
5917.093	A?	000	5925.460		0000
5917.365	–, A?	0000 N	5925.799	A?	0000
5917.605	A (wv)	0	5926.048		0000
5917.827		0000	5926.244		0000
5918.022		0000	5926.418		0000
5918.225	A (wv)	00 d	5926.835	A (wv)	000
5918.420	A?	0000	5927.040	A?,-	0000
5918.635	A (wv)	4	5927.425		0000
5918.773	Ti	0	5927.750		0000
5918.980		0000 N	5928.013	Fe	2
5919.175	A (wv)	000	5928.280		000
5919.276	A (wv)	5	5928.510	A (wv)	2
5919.505		0000	5928.740		0000
5919.585	A?	0000	5928.890	A?	0000
5919.860 s	A (wv)	7	5929.056	A (wv)	000
5920.060	A?	0000	5929.100		000
5920.395	A (wv)	00	5929.350	A (wv)	00
5920.546	A?	0000	5929.630	A (wv)	000
5920.776	A (wv)	1	5929.898	Fe	2
5920.981	A?	0000	5930.145	A?	0000
5921.374	A (wv)	00	5930.225		0000
5921.558	A?	0000 N	5930.406 s	Fe	6
5921.878	A (wv)	0	5930.640		0000
5922.100	A?	0000	5930.815	A (wv)	00
5922.334	Ti	0	5930.980		0000

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
5931.230	A (wv)	00	5942.635	A (wv)	1
5932.118		0000	5942.789	A (wv)	3
5932.306	A (wv)	5	5942.950		0000
5932.456	A?	0000	5943.120		0000
5932.699	A?	0000	5943.330		0000
5932.998	A (wv)	2	5943.605		000
5933.233	A (wv)	0000	5943.815		00
5933.425		0000	5944.065		0000
5933.670	A?	0000	5944.230		0000
5933.872	A (wv)	000	5944.530	A (wv)	1
5934.024		000	5944.713		0000
5934.140	A (wv)	000	5944.945	A (wv)	1
5934.300	A (wv)	00	5945.230		0000
5934.490		0000	5945.463	A (wv)	00
5934.655		0000	5945.530	A (wv)	00
5934.881 s	Fe	5	5945.865	A (wv)	1
5935.165		0000	5946.104	A?	0000
5935.400	A (wv)	00	5946.223	A (wv)	3
5935.625		000	5946.485	A?	0000
5935.863	A?	0000	5946.685		000
5936.038	A (wv)	0	5946.864	A (wv)	000
5936.278		0000	5947.062	A (wv)	1
5936.428	A?	0000 N	5947.283	A (wv)	2
5937.183		0000	5947.500		0000
5937.345	A (wv)	0000	5947.644	A (wv)	000
5937.523	A (wv)	000	5947.730		00
5937.670	A (wv)	000	5947.955	A?	0000
5938.035		000	5948.195	A?	0000
5938.160	A (wv)	000	5948.452	A (wv)	00
5938.270	A (wv)	0	5948.765 s	Si	6
5938.500	A (wv)	000	5948.995	A (wv)	000
5938.810	A (wv)	00	5949.240	A (wv)	0000
5938.965		0000	5949.390	A (wv)	2
5939.455		0000 N	5949.566	Fe	1
5939.633		0000	5949.794	A (wv)	000
5939.967		0000	5949.880	A (wv),-	000
5940.185	A (wv)	0	5950.040	A (wv)	0
5940.400	A?,-	000	5950.229		0000
5940.640	A (wv)	1	5950.356	A (wv),-	00
5940.875		0000 N	5950.560	A (wv)	0
5941.091	A (wv)	00	5950.688		0000
5941.210		0	5951.070	A?	0000
5941.290	A (wv)	5	5951.181	A (wv)	00
5941.470	A (wv)	000	5951.310		0000
5941.630	A?	0000	5951.440	A (wv)	000
5941.845	A (wv)	2	5951.530	A (wv)	000
5941.985	Ti	00	5951.718	A (wv)	0
5942.220	A?	0000	5952.015		0000
5942.399		0000	5952.406		0000
5942.500	A (wv)	000	5952.578	A?	000

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
5952.740		000	5965.163	A (wv)	00
5952.943	Fe	4	5965.370	A?	0000
5953.207		0000 N	5965.543	A?	0000
5953.386	Ti	1	5965.740		0000
5953.583	A?	0000	5966.055	Ti, A?	2
5953.680	A (wv)	00	5966.223		0000
5953.935		0000	5966.430	A (wv)	000
5954.200	A?	000	5966.560	A (wv)	0
5954.595	A (wv)	000	5966.706	A?	0000
5954.906		0000	5966.885	A (wv)	1
5955.170	A (wv)	1	5967.218	A?	000
5955.331		0000	5967.540	A (wv)	00
5955.570		0000	5967.720		0000
5955.890		0000	5967.880		000
5956.039	A (wv)	000	5968.058	A (wv)	2
5956.252	A (wv)	000	5968.280	A (wv)	000
5956.364	A (wv)	0000	5968.495	A (wv)	2
5956.573	A (wv)	0	5968.630		0000
5956.715		0000	5968.882	A?	0000
5956.923 s	Fe	4	5969.260	A (wv)	0
5957.175		0000	5969.510	A?	0000
5957.253		0000	5969.795		000
5957.365	A?	0000	5970.046	A?	0000
5957.790		0000	5970.280	A (wv)	0
5958.098	A (wv)	1	5970.480	A?	000
5958.297		0000	5970.714		0000
5958.460	A (wv),-	1	5970.908	A (wv)	000
5958.565		00	5971.182		0000
5958.840		1	5971.366		0000
5959.025	A?	0000	5971.557	A (wv)	1
5959.380		000	5971.990		0000
5959.535	A?	0000	5972.970		0000
5959.830		000	5973.203		0000
5959.940		000	5973.578		0000
5960.200	A?	0	5973.695		0000
5960.560		0000	5974.094	N	0000
5960.800		0000	5974.495		0
5961.444		0000	5974.812	N	0000
5961.665	A (wv)	0	5975.054		0000
5961.955		0000	5975.330	A (wv)	1
5962.110		0000	5975.413		0000
5962.390	A?	000	5975.575 s	Fe	3
5962.516	A?	0000	5975.820		0000
5962.690	A (wv)	0	5976.046		0000
5962.840		0000	5976.150	A?	000
5963.134		0000	5976.387		0000
5963.326		0000	5976.504		0000
5963.496	A?	000	5976.694	A (wv)	00
5963.790		0000	5976.730	-,A?	0
5964.826		0000	5977.007 s	Fe	4

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
5977.252 s	A (wv)	1 d?	5989.313	A?	0000
5977.513		0000	5989.510	A (wv)	0
5977.655	A (wv)	00 N	5989.788		0000
5978.033	A (wv)	0	5990.290		000
5978.292		0000	5990.595		0000
5978.365	A?	000	5990.830	A (wv)	00
5978.560		0000	5991.070	A (wv)	0
5978.768	Ti	1	5991.237		0000 N
5979.012		0000	5991.600		2
5979.135		000 N	5991.790		0000
5979.455	A?	0000 N	5992.010		000
5979.527		0000	5992.218	A (wv)	0
5979.915		0000 N d?	5992.409		0000
5980.395	A (wv),-	00	5992.555		0000
5980.740	A (wv)	000	5992.900		0000
5980.965	A?	0000	5993.275	A (wv)	00
5981.043		0000	5993.674		0000
5981.450	A?	00	5993.875		0000
5981.614		0000	5994.135	A (wv)	00
5981.930	A?	0000	5994.563		0000
5982.085		000	5994.756	A (wv)	0
5982.200		0000	5995.491	A?	0000 N
5982.530		000	5995.916		0000
5982.838		0000 N	5996.164		000 N
5983.098	A (wv)	00	5996.247		0000
5983.525	A (wv)	000	5996.445		0000
5983.650		0000	5996.725		0000
5983.908	Fe	5	5996.963	Ni	1
5984.195	A?	000	5997.195		0000
5984.285		0000	5997.438		0000
5984.495		000	5997.578	A (wv)	0
5984.660		0000	5997.826	A, Ni	0
5984.810		0000	5998.002	Fe	2
5985.040 s	Fe	6	5998.442		000
5985.435	A (wv)	0	5998.760		0000
5985.615	A?	0000	5999.115		0000
5985.731	A?	0000	5999.204		000
5985.924	A?	0000 N	5999.436	A (wv)	00
5986.350		000	5999.647		0000 N
5986.674		0000	5999.920	Ti, A (wv)	0
5986.975		0000 N	6000.269		0000
5987.290 s	Fe	5	6000.370	A (wv)	00
5987.525		0000	6000.900	A?	00
5987.774		0000	6001.345	A?	000
5988.048	A?	0000 N d?	6001.765	A (wv)	000
5988.325	A (wv)	000	6002.375	A (wv)	000
5988.574	A?	0000	6002.870	A (wv)	00
5988.785	A (wv)	0	6002.970		0000 N
5988.985		000	6003.239 s	Fe	6
5989.180		0000	6003.538		0000

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
6004.095	A (wv)	000 N	6020.232 } s		2
6004.603		0000 N	6020.401 }	Fe	4
6004.895	A (wv)	00	6020.610		0000
6005.098	A?	0000	6020.873		0000
6005.228		0000	6022.016 s	Mn	6
6005.586		0000	6022.440		0000
6005.770	Fe	1	6022.690		0000
6006.003		0000	6023.239		0000
6006.280	A?	000 N	6024.171		0000
6006.605	A?	00	6024.281 s	Fe	7
6007.080		0000	6024.459		0000
6007.255		0000	6025.425		0000
6007.540	Ni	1	6025.000	A?	00
6007.760		0000	6026.380	A?	0000
6007.935		000	6026.615	A?	0000
6008.186 s	Fe	4	6026.900	A?	0000
6008.450		0000	6027.040		0000
6008.556		0000	6027.274 s	Fe	4
6008.785 s	Fe	6	6027.485		0000
6009.031		0000	6027.650		0000
6009.580	A (wv)	000	6027.948	A,-	000 N
6010.066	A?	0000	6028.220	A	000
6011.001		0000 N	6028.490	A?	000 Nd?
6011.745		0000	6028.720		0000
6011.980		0000	6029.100		0000
6012.210		0000 N	6029.500		0000 N
6012.450	Ni	1	6030.110	A (wv),-	0
6012.660		000	6030.550		0000
6012.996		000 N	6030.860		0000 N
6013.416		000 N	6031.240		00 N
6013.715 s	Mn	6	6031.520		0000 N
6014.130		0000 N	6031.932		0000
6014.641		0000	6032.176		0000
6015.058		0000 N d?	6032.374		0000
6015.258		0000	6032.885		0000 N
6015.475		000	6033.530		0000
6015.830	A?	0000	6033.810		0000 N
6016.070	A?	000	6034.265	A?	0
6016.233		0000	6034.440		0000
6016.624		0000	6034.715		0000 N
6016.861 s	Mn	6	6035.137		0000 N
6017.140		0000	6035.575	A?	0
6017.080		0000	6036.121		0000 N
6018.524		0	6036.434		0000
6018.760		0000	6036.685	A?	0
6019.039	A?	0000	6037.009		0000
6019.372	A (wv)	000	6037.687		0000
6019.596	Ba?	000	6039.540		0000
6019.795		0000 N	6039.693		0000
6020.000		0000 N	6039.808		0000

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
6039.953	V	0	6063.316		0000
6040.190		0000	6063.522		0000 N
6042.198		0000	6064.258		000 N
6042.315 s	Fe	3	6064.853	Ti	00
6042.480		0000	6065.709 s	Fe	7
6042.942		0000	6066.020		0000
6043.164		0000	6067.492		0000
6043.640		000	6067.850		000
6043.843		0000	6068.172		0000
6044.258		0000 N	6068.704		0000
6045.705		000	6069.931		0000
6045.985		0000	6070.303		0000
6046.245		0 N	6071.575		0000
6047.280	A?	0000 N	6071.970		0000
6047.880		0000	6072.238		0000
6048.495	A?	0000 N	6073.410		0000
6049.011	A?	0000 N	6073.772		0000
6049.337		000 N	6074.230		0000
6051.245		0000 N	6075.739		0000
6052.061		0000 N	6076.360		000 Nd?
6052.828		000	6076.820		0000 N
6052.906		00	6077.120		00
6053.153		0000 N	6077.480		0000 N
6053.233		0000 N	6077.702		0000 N
6053.476		0000 N	6078.060		000 N
6053.690		000	6078.410		0000 N
6053.912	Ni	0	6078.710 s	Fe	5
6054.125		0000	6078.978		000 N
6054.290	A?	00	6079.227 s	Fe	2
6055.310		000	6080.230		000
6055.620		000	6080.450		0000
6055.980		0000 N	6080.794		0000 N
6056.227 s	Fe	5	6081.422		0000 N
6056.565		000	6081.665	V	0
6056.987		0000 N	6081.930		0000
6057.110		0000	6082.050		0000
6057.475		00 N	6082.640	Co	000 Nd?
6058.080		0000	6082.930	Fe	1
6058.385		000 N d?	6083.915		0000 N
6058.874		0000	6084.325		0
6059.484		0000	6085.470	Ti, Fe	2
6059.970		0000	6085.656		0000
6060.340		0000	6086.128		0000
6060.853		0000	6086.500	Ni	1
6061.037		0000	6086.885		0000 N
6061.870		000	6088.047		00 N
6062.455		0000 N	6088.490		0000 N
6062.704		0000	6089.275		0000 N
6062.910		000	6089.538		0000
6063.080		0	6089.787	Fe	1

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ON THE PERFORMANCE OF AN AUXILIARY LENS FOR SPECTROGRAPHIC INVESTIGATIONS WITH THE THIRTY-INCH REFRACTOR OF THE PULKOWA OBSERVATORY.

By A. BÉLOPOLSKY.

In order to better adapt the thirty-inch refractor of the Pulkowa Observatory to spectrographic investigations, an auxiliary lens has recently been constructed, according to the plan proposed by Professor Keeler.[1] The lens has a diameter of 60^{mm}, and it is placed $1^{m}.070$ above the focus for the F line of the thirty-inch objective. According to Herr Steinheil, who made the lens, the radii of the surfaces are as follows:

$421^{mm}.7$	Flint
421 .7	
302 .5	Crown

The lenses are cemented together.

The lens is secured at a place where there was formerly a large prism, which reflected the light from the objective at right angles into a direct-vision spectroscope. By means of a pinion it can be moved axially in the cone of rays, and its position is indicated by a divided head. Screws are also provided for the necessary adjustments. Since at certain times in Pulkowa optical surfaces become heavily clouded with moisture, the lens is so mounted with a bayonet clip that it can be removed from the tube of the refractor for examination and replaced without disturbing the adjustments.

In order to estimate the advantages afforded by the lens, I made a series of spectrograms of α Persei and α Cassiopeiae, the slit-width and time of exposure remaining unchanged. It was found that the introduction of the lens shortened the focal length of the refractor for the $H\gamma$ rays by 10^{mm}, an amount which is well within the range of the collimator slide (60^{mm}). The length

[1] *Ap. J.* 1, 101, 1895.

of the spectrum was considerably increased; without the lens the spectrum of α Persei extended from λ 441 to λ 423 (spectrograph No.3), while with the lens it extended from λ 486 to λ 400. For α Cassiopeiae the lengths of the photographed spectra were as follows:

Without lens, - - λ 438—λ 423
With lens, - - - λ 430—λ 410

Measurement of the width of the spectra gave the following results:

α PERSEI, COLLIMATOR 22.5.

With Lens			Without Lens		
λ	Measured Width	Reduced Width	λ	Measured Width	Reduced Width
4004	0mm.12	−0mm.06	.....	.....	.....
4045	0 .16	−0 .02	.....	.....	.....
4101	0 .18	0 .00	.....	.....	.....
4227	0 .29	+0 .11	4227	0mm.19	+0mm.01
4272	0 .32	+0 .14	4272	0 .27	+0 .09
4341	0 .33	+0 .15	4341	0 .40	+0 .22
4405	0 .36	+0 .18	4384	0 .56	+0 .38
455	0 .40	+0 .22	441	0 .67	+0 .49
467	0 .41	+0 .23	.....	.....	.....
482	0 .33	+0 .15	.....	.....	.....
486	0 .19	+0 .01	.....	.....	.....

Since the width depends partly upon the rate of the driving clock, all the above measures are reduced to a width of 0mm.18.

α CASSIOPEIAE, COLLIMATOR 27.0.

With Lens			Without Lens		
λ	Measured Width	Reduced Width	λ	Measured Width	Reduced Width
427	0mm.19	0mm.00	4227	0mm.20	0mm.05
433	0 .22	0 .03	4235	0 .15	0 .00
435	0 .25	0 .06	4261	0 .18	0 .03
445	0 .25	0 .06	428	0 .20	0 .05
455	0 .26	0 .07	431	0 .30	0 .07
460	0 .26	0 .07	434	0 .37	0 .22
465	0 .26	0 .07	438	0 .50	0 .35
470	0 .25	0 .06	.....	.....	.....
480	0 .23	0 .04	.....	.....	.....

(Reduced to a width of 0mm.19.)

For comparison I give the reduced widths of spectrograms obtained with the same spectrograph mounted on the large photographic telescope:

λ	Width
410	$0^{mm}.05$
420	0 .07
434	0 .06
441	0 .07
480	0 .03

The intensity of the spectrograms is fairly uniform throughout the whole spectrum, although in comparison with the intensity of a short interval (λ 423–λ 427) of a spectrogram which was taken without the lens, the latter is somewhat the greater. This circumstance may be caused in two ways: first, the (observed) rays may not be so accurately united in a point; second, the correcting lens may absorb part of the light.

A further advantage of the lens is that with it the star can be seen on the slit, a circumstance which greatly facilitates the task of guiding. No difference can be perceived between the spectral lines obtained with and without the lens.

PULKOWA, December 1895.

Minor Contributions and Notes.

MISS BRUCE'S GIFT TO THE ASTROPHYSICAL JOURNAL.

The Editors take pleasure in announcing that Miss Catherine W. Bruce of New York has presented to the University of Chicago the sum of one thousand dollars, to be used for the purpose of providing illustrations for The Astrophysical Journal. In view of the important part played by photography in astrophysical work at the present time, the possibility thus afforded of reproducing the best results of recent investigations may be expected to add materially to the value of the Journal. Miss Bruce's numerous benefactions to astronomy in both Europe and America have brought her the gratitude of many persons, among whom the Editors and readers of this Journal may now be counted.

ON MR. F. W. VERY'S REMARKS CONCERNING MY NOTE ON LAWS OF RADIATION.

Before entering upon a discussion of the experimental basis of Mr. Very's objections to the relations I have deduced from the observed energy spectra of iron oxide, I wish to point out that but one of the two relations arrived at can be called a principal of radiation, namely the law $\lambda_{max.} \times \text{Abs. T.} = \text{Const.}$ The other relation, $\lambda_1 \times \lambda_2 = \lambda^2_{max.}$ which, according to my observations, holds only in the vicinity of the maximum, can hardly be considered a general principle. As a matter of fact, I have regarded this relation only as a very useful means of determining from the values of λ_1 and λ_2 the exact position of the maximum. Determinations of the maximum made in this way are of great accuracy, for slight errors of the points of observation accumulated near the maximum are of much less effect in displacing its position than they would be if no similar relation existed.

Whether this relation and the other law proposed in my paper are accurate also for temperatures lower than 228° C. and higher than 1009° C. is a question whose probability I have discussed in my paper. For lower temperatures the form and the maximum of the normal

curves were greatly affected by the strong absorption of water-vapor of the air at $5^{\mu}.9$ and $6^{\mu}.5$, which I have invariably observed, even in dry weather. Therefore the accuracy of the maximum determined was not comparable with that of curves made at higher temperatures.

Mr. Very's objections to the law $\lambda_{max.} \times$ Abs. T. = Const. are based upon two energy-curves, one being that of the positive carbon of the electric arc, and the other a curve of lampblack for the temperature 318° abs. or 45° C.

As regards the second, the maximum of which Mr. Very considers to lie at $7^{\mu}.3$, I cannot find any details in the literature of the subject. Langley[1] only states that the position of the maximum of the prismatic curve of lampblack at 40° C. is 38° 2′ with a rock-salt prism of 60° set at minimum deviation. According to the dispersion curve of rock-salt observed by Rubens and also determined by myself[2] this deviation corresponds to a wave-length of $7^{\mu}.32$. It therefore seems that Mr. Very has not calculated the normal curve, whose maximum lies at much greater wave-lengths than that corresponding to the maximum of the prismatic curve. Now Langley[3] gives details of two energy-spectra of solid bodies: one at the temperature 178° C., the other at —2° C. I have calculated from these data the ordinates of the normal curves, which may be found from the ordinates of the prismatic curves given by Langley by multiplying them by $\frac{d\delta}{d\lambda}$, where δ is the observed minimum deviation and λ is the corresponding wave-length. I used for this purpose the dispersion curve of rock-salt observed by Langley and determined for the greater wave-lengths by Rubens and myself. This curve, although not known with the same accuracy as that of fluor-spar, seems accurate enough for the purpose of making this calculation.

The two series observed for the temperature —2° C. and given by Langley, do not lead to a determination of the maximum of the normal curve. One of the series gives points oscillating up and down and therefore indicating no certain maximum. The other series gives ordinates which increase from $6^{\mu}.9$ to $8^{\mu}.5$, the last observed point which can be reduced to the normal curve. At the point 36° 00′, which cannot be reduced because the dispersion determinations do not go so far, the energy has probably decreased again. The conclusion,

[1] S. P. LANGLEY, *Ann. Chim. et Phys.* VI., 9, 1886, p. 469.

[2] H. RUBENS, *Wied. Ann.* **54**, 482; F. PASCHEN, *Wied. Ann.* **53**, 301.

[3] S. P. LANGLEY, *loc. cit.* pp. 457–467.

if any conclusion can be drawn from this, is that the maximum of the normal curve of lampblack at -2° C. lies at wave-lengths greater than $8^\mu.5$. Therefore $\lambda_{max.} \times$ Abs. T. is greater than 8.5×271, or 2304, which does not seem to contradict my law.

The numerical data of the curve for 170° given by Langley, when treated in a similar way, give a curve which is interrupted in a serious manner by the strong absorption band of water-vapor at 6^μ. From the few published points I could only find that the curve rises again on the less refrangible side of the absorption band to a height a little greater than that on the other side of the band, the point $38^\circ\ 0'$ (with a prism of $59^\circ\ 57'.6$ angle), or $7^\mu.32$, having a height of 4.36 if the point $38^\circ\ 45'$, or $5^\mu.1$, has a height of 4.18. The absorption band lies between these points, and the energy falls off on both sides. No other suitable points occur in this region, and those within the band itself cannot be employed. Assuming these two points to be of equal height within the limits of error, I find by calculation $\lambda_{max.} = \sqrt{7.32 \times 5.1} = 6^\mu.11$, which gives $\lambda_{max.} \times$ Abs. $T. = 6.11 \times 451 = 2806$.

Considering the great difficulty of calculating the maximum from a very small number of observed points in a curve which is greatly disturbed by the broad absorption band falling exactly upon the maximum, this value does not seem to be in contradiction with my statements, as it is even larger than my law requires. Now Langley finds the maximum of the prismatic spectrum of this curve to be $38^\circ\ 37'$ (angle of prism $60^\circ\ 00'$).[1] $6^\mu.11$ would correspond to a deviation of $38^\circ\ 27'$ with the same prism. The displacement of the maximum to the less refrangible side, when reduced to the normal curve, therefore amounts in this case to $10'$. In the curve for 40° C. referred to by Mr. Very, this displacement must be still greater, because the energy rises less rapidly from the greater wave-lengths to the maximum. Assuming $10'$ displacement for this curve also, the maximum of the normal curve for 40° C. would have a deviation less than $38^\circ\ 2' - 10' = 37^\circ\ 52'$ (angle of prism 60°), or a wave-length greater than $7^\mu.73$. Therefore $\lambda_{max.} \times$ Abs. T. in this case must be greater than $7.73 \times 313 = 2420$, which does not seem to contradict my relation.

Assuming my law to be accurate also for the highest temperatures I have calculated a value of the Sun's temperature. I agree with Mr.

[1] This value is given by Langley on p. 469, *Ann. Chim. et Phys.* VI., 9, 1886. It is only an estimate, on account of the interference of the absorption band with the maximum of the prismatic curve.

Very that this extrapolation transcends actual knowledge. But there can be no doubt that the determinations of the temperature of the Sun and the electric arc made by Messrs. Gray and Wilson also belong to this class of work, as they were made by a very large extrapolation of empirical laws which of course also transcends actual knowledge. Nevertheless Mr. Very takes from them the temperature of the electric arc for the curve of the positive carbon, which is his second instance of deviation from my law.

From the data published by Langley[1] it is impossible to calculate either the position of the maximum or the form of the curve in its neighborhood with any accuracy, as but two points are given near enough to the maximum of the normal curve. A small error in these determinations would displace the maximum to a very considerable extent. These two points are 40° 5′ (angle of prism 60°), or 0μ.933, and 39° 54′, or 1μ.067, with the respective heights 207 and 211 reduced to the normal scale. The next points on both sides are too far away to be used in the determination of the maximum. Assuming these two points to be correct, and their ordinates to be of equal height within the limits of error, $\lambda_{max.}$ would be $\sqrt{1.067 \times 0.933} = 0^{\mu}.998$. According to my relation this would give for the carbon a temperature of $\frac{2727}{0.998} = 2729°$ abs. This would represent a lower limit for that temperature, because in my observations $\lambda_{max.} \times$ Abs. T. increases a little with the temperature, and therefore 2727, the highest value observed for 1009° C., might still be a little too low. Further, it seems to me very difficult to screen off all the light except that from the small point of greatest brilliancy in the arc. If light from the cooler parts of the arc also falls upon the bolometer, the greater wave-lengths would have ordinates relatively too great, and the maximum would suffer a corresponding displacement. This might also be a cause of lowering the temperature calculated in this way. The calculated temperature of the positive carbon of the arc does not seem to be an improbable one. But the published data are too few and seem too incomplete to warrant any conclusions. Langley himself says of this curve: "The observations were not repeated to obtain such a thorough comparison as would be desirable . . . we will give them here under the caution that they are to be considered only first approximations." If Mr. Very has used nothing but these observations (the only ones which he quotes in his note) I do not believe that his objections are well founded. Neither

[1] S. P. LANGLEY, *Am. Jour. Sci.* (3), **38**, 1889, p. 438.

the determination of the temperature nor the observation of the maximum of the curve would to any considerable degree be comparable in accuracy with my observations.

F. PASCHEN.

TEST OF THE FORTY-INCH OBJECTIVE OF THE YERKES OBSERVATORY.

IN September, 1895, Mr. Alvan G. Clark reported that the forty-inch object glass of the Yerkes Observatory was completed. By the terms of the contract it was necessary to have the objective examined by an "expert agent" before its acceptance by the Observatory, and on account of my familiarity with the Lick telescope, I was invited by Professor Hale to accompany him to Boston, and test the lens in the capacity above mentioned.

Our examination was made on the nights of October 17, 18, 19 and 21, 1895. The temporary equatorial mounting for the lens stands in the open air near Mr. Clark's factory in Cambridgeport; it is the same mounting which was used for testing the Princeton, Washington and Lick objectives, the masonry pier having been twice built higher to accommodate the progressively increasing length of tube required for these different telescopes. There is no clockwork, and the observer has to follow a star by pressing on two handles which project from the lower end of the tube; usually he is aided by an assistant. The motion in right ascension is as smooth as could be expected, but it is not a perfectly easy matter to keep an equatorial star in the center of the field with a high power.

The construction of the objective is quite similar to that of the Lick telescope, the lenses being separated by a space of about seven inches. Both lenses are remarkably free from air-bubbles, "stones" and striæ. Their weight, with that of the cast-iron cell in which they are mounted, is one thousand pounds.

Under the atmospheric conditions which generally prevail at Boston, it is quite impossible to test so large an objective as the forty-inch with the definite results that can be obtained in the case of a smaller aperture or a steadier atmosphere. It is necessary to make large allowances for atmospheric disturbance. Mr. Clark informs me that at his factory he has never seen diffraction rings around a star disk, although they are easily seen with the Lick telescope in its present situation. Hence

it was extremely difficult to estimate what the undisturbed distribution of light in the image at the focus would be, and it was useless to attempt the observation of close double stars near the theoretical limit of resolution, since this is merely another method of estimating the diameter of the central disk of the diffraction pattern. With a knife-edge at the focus (Foucault's test), the objective appeared to be filled with tremulous patches of light, constantly changing their position, but on the whole representing a distribution of light which seemed to be uniform. The most satisfactory test that could be made under the actual conditions was to examine the cross-section of the cone of rays at different points inside and outside of the focus, and for this purpose the makers had provided a long draw-tube, sliding by hand with a very smooth and easy motion.

On the first night a slight elongation of the expanded star disk led us to experiment on the effect of changing the relative positions of the lenses. It was found that when the great tube was pointed to the nadir, a number of men, by pressing upward on the crown lens so as to relieve the supports of its weight, could turn the lens without removing it from the cell; thus the experiments were made without much trouble or labor. In certain positions of the crown lens the elongation of the image became quite pronounced, and in no position was it less than at first. Finally, on October 21, the lens was restored to its original position, and then both lenses were turned 90°, the operation in this case requiring their removal from the cell. In the evening the sky was very clear and the definition exceptionally good;—perhaps nearly as good as it ever is at the place where the telescope was mounted. The last change in the lens had also been an improvement. The expanded star disk was round inside and outside of the focus, uniformly illuminated, and free from wings or other appendages. Good images at the focus were obtained of stars at widely different altitudes near the meridian, the definition being in my opinion, with due allowance for atmospheric disturbance, equal to that of the Lick telescope, while the brightness of the image was of course considerably greater than with the latter instrument. With a low power the nebula of Orion was a wonderful object, and the bluish green color in the Huyghenian region was more vivid than I have ever seen it in an extended nebula. The minute stars in the trapezium discovered with the Lick telescope were probably, though not certainly seen, the imperfections of the mounting interfering greatly with this class of observations. Sirius was

examined when still at a considerable distance east of the meridian, and an unsuccessful search was made for the companion. The absence of ghosts and the small amount of diffuse light when this brilliant star was in the field were particularly noted. The color correction of the forty-inch objective is, according to my best recollection, almost precisely the same as that of the Lick objective.

From these tests it appears that the character of the image varies with the position of the lenses relatively to each other, and, to a less extent, with the position of the objective as a whole relatively to its cell. It is probable that flexure of the lenses is the principal cause of the observed changes, and it is interesting to note that there is here evidence, for the first time, that we are approaching the limit of size in the construction of great objectives. A more complete investigation of the subject can be made only after the objective is permanently mounted, so that stars can be observed at widely different hour angles. The flexure seems to be of the kind frequently noted in the construction of large mirrors, which are found to give the best definition when a certain diameter is placed vertical. It is not likely that the effects of flexure will be appreciable in the case of the forty-inch objective when the lenses are properly adjusted; for larger objectives, it is possible that the limit above referred to may be extended by providing their cells with a position circle, so that they can be rotated about the axis of the telescope tube.

All the tests described above were made jointly by Professor Hale and myself, and the conclusions at which we arrived are substantially the same.

JAMES E. KEELER.

NOTE ON THE APPLICATION OF MESSRS. JEWELL, HUMPHREYS AND MOHLER'S RESULTS TO CERTAIN PROBLEMS OF ASTROPHYSICS.

THE fact that the wave-length of a spectral line is a function of the pressure of the gas or vapor producing it, is obviously of prime importance in astrophysics. In spite of certain well-established phenomena, such as the unsymmetrical reversal of metallic lines in the arc and the interesting observations by Ebert of a change in the position of a line when the amount of material in a flame is varied, the Fraunhofer lines have been regarded as fixed marks of reference, subject to no possible

change in position. Moreover, but little evidence has been advanced to show that any of the Fraunhofer lines vary in intensity, though that a secular change is going on is indicated by the variety in type of stellar spectra. Some remarkably fine photographs of the *b* group in the solar spectrum, made by the Rev. Walter Sidgreaves in 1891 with a Rowland plane grating of 14,438 lines to the inch, seemed to show that the line No. 17 of Professor Winlock's maps in the *Proceedings of the American Academy* had decreased in intensity.[1] Professor Hastings' observations in 1873 of the different intensities of certain lines at the center of the solar disk and near the limb may also be mentioned in this connection.[2] Ångström had previously pointed out some apparent variations of a more general character.[3] It seems, however, to have remained for Mr. Jewell to establish with certainty a variation in the intensity of an absorption line in the general spectrum of the Sun. Every photograph of the solar spectrum taken with high dispersion must now be regarded as a document of great value, which may ultimately reveal irregular or periodic changes in the condition of the gases and vapors of the solar atmosphere.

The double reversal of the H and K lines was discovered almost simultaneously by M. Deslandres and myself in 1891. In the following year I pointed out the lack of symmetry in the reversals,[4] without offering an explanation of this peculiarity. In the same year M. Deslandres[5] and the Rev. Sidgreaves found the double reversals in the spectrum of general sunlight, and showed that the Sun might therefore be classed as a bright line star. M. Deslandres has recently investigated the displacement of the central absorption line of the double reversal, and ascribes it to motion of the absorbing gas.[6]

It now appears that all of these observations were anticipated by Mr. Jewell, who discovered the double reversals in the general spectrum and in various parts of the solar disk in 1889. He detected the displacement of the central line, and somewhat later attributed it to motion in the line of sight.

In connection with Mr. Jewell's paper it will be of interest to consider some of the results arrived at by M. Deslandres in the article already referred to. After remarking that the dark absorption line is usually central over faculæ, M. Deslandres adds: "En dehor des facu-

[1] *A. and A.* 11, 79, 1892.
[2] *Nat.* 8, 77, 1873.
[3] *C. R.* 63, 648, 1866.
[4] *A. and A.* 11, 813, 1892.
[5] *C. R.* 1892.
[6] *C. R.* 119, 457.

les, par contre, la dissymétrie des composantes brillantes, qui, d'ailleurs, sont faibles, est le cas le plus fréquent; elle est nette, en général, au moins sur les trois quarts de la surface, dans le sens de la lumière générale, et est plus ou moins accentuée, étant quelquefois telle que la composante rouge est invisible. Elle se présente aussi bien près de l'équateur que près des pôles, mais très rarement à une faible distance du bord."

My own photographs seem to show that the disappearance of the red component of the emission line is not always due to the displacement of the central absorption line, but usually simply results from the fact that this component is less brilliant than the more refrangible one. Mr. Jewell's curve (Fig. 7, p. 100) closely represents the distribution of light in the doubly-reversed line.

Mr. Jewell and M. Deslandres consider that the displacement of the central line is due to motion of the absorbing gas. In M. Deslandres' words, "L'ensemble des faits précédents peut s'expliquer par un mouvement général de circulation verticale et horizontale des couches hautes et basses de la chromosphère, analogue à celui que présente notre atmosphère. Les couches basses s'élèveraient et seraient attirées vers l'équateur, comme les vents alizés, d'où un rapprochement vers la Terre; les couches élevées auraient un mouvement inverse." M. Deslandres endeavored to determine the absolute displacement of the central dark absorption line at the center of the disk and the corresponding emission line in the chromosphere at the limb by comparing them with lines in the spark spectrum of iron. He found an apparent slight shift of certain parts of the absorption line toward the red, with respect to the iron lines, while the emission line of the chromosphere "présentait un déplacement moindre ou inverse." M. Deslandres concludes that the dispersion employed (4th order of a Rowland grating, with observing telescope of $1^{m}.30$ focus) was insufficient for the purpose. It was noticed, however, that "les composantes brillantes de la raie du calcium dans l'étincelle présentent aussi une légère dissymétrie dans le même sens que la raie solaire," and it is suggested that these similar displacements may be due to similar causes.[1]

We now know that the reversed line in the spark spectrum should be unsymmetrical, if the pressure conditions in the arc and spark are similar. The emission line, produced by the radiation of the vapors in the central part of the spark, should be displaced — not, as M. Des-

[1] *C. R.* 119, 459, 1894.

landres' words would seem to indicate, toward the violet, but toward the red. The central line of absorption would thus appear to be displaced toward the violet with respect to the emission line, an appearance exactly the reverse of that existing in the spectrum of the solar surface. It therefore seems to be impossible to account for the lack of symmetry of the H and K reversals in the Sun by ascribing it to the different pressures of the upper and lower strata of the chromosphere. That such a difference exists is indicated by the broadening of the lines at the lower level. There is therefore in all probability a displacement of the emission lines toward the red, due to this cause, but it is partly or wholly overcome by a displacement in the opposite direction, due apparently to motion in the line of sight.

But even this latter explanation is not free from difficulties. M. Deslandres' suggestion that the vapors in the lower stratum of the chromosphere have an ascending motion, and are drawn toward the equator, while the vapors of the upper stratum move inversely, would seem to apply perfectly, were it not for the fact that the displacement of the central absorption line, according to his observations, is well defined over at least three-quarters of the surface, and is as commonly present near the equator as near the poles, though rarely at a slight distance from the limb. In other words, the vapor which produces the central absorption line, on whatever part of the surface it may be found (except near the limb) is moving away from the observer. In the absence of further information, there would seem to be as much evidence of descending vapor flowing east and west from the central meridian (which is manifestly out of the question), as there is of descending vapor flowing north and south from the equator. Many solar theories have postulated such a current, but hitherto its existence has not been certainly established. It will be a matter of extreme interest to investigate this question further. I very much regret that the numerous photographs of the H and K reversals on the Sun's surface made at the Kenwood Observatory during the last five years have been taken with a dispersion insufficient to permit of their use in a case of this kind. The solar spectroscope now in process of construction for the forty-inch Yerkes telescope will, it is hoped, be sufficiently powerful for the purpose.

The difference in behavior of H and K and the blue line of calcium discovered by Messrs. Jewell, Humphreys and Mohler seems to support Lockyer's views as to the dissociation of calcium in the arc

and Sun. The remarkable variations of the calcium spectrum with temperature have long been known, principally through the investigations of Lockyer. The writer has shown that the H and K lines are produced at the temperature of burning magnesium and in the oxy-coal-gas flame. They could not be photographed in the spectrum of the Bunsen burner, though an exposure of sixty-four hours was given. Since these experiments were made I have been informed by Professor Eder that his own efforts to photograph the lines in the Bunsen burner were no more successful, though an optical train of quartz and fluor-spar was employed. It would thus appear that the temperature of dissociation of calcium is between that of the Bunsen burner and that of the oxy-coal-gas flame. The high molecular weight of calcium has hitherto conflicted with our belief in the presence of this metal in prominences. If, however, it be granted that dissociation can be brought about by temperatures even lower than that of the arc, the difficulty is very greatly lessened.

Although it has been shown that the range of pressure in the reversing layer is considerable, it would probably be premature to argue that its depth must therefore be comparable with that of the corona. There seems as yet to be no certain evidence that any absorption line in the solar spectrum has its origin above the upper limits of the chromosphere. Mr. Jewell suggests that the central dark line of the H and K reversals is produced by the corona. In this case it should show a very decided relative shift toward the violet, due to the different pressures of the chromosphere and corona, and be subject to relative displacements near the east and west limbs of the Sun toward the violet and red respectively, due to the difference between the components in the line of sight of the velocities of rotation of the chromosphere and corona. These displacements would be complicated with those resulting from internal motions of the coronal vapors, but a careful study of the H and K reversals in various parts of the solar surface, made with very high dispersion, would probably decide the question. However, the close similarity of the central absorption line on the disk and the emission line in the upper part of the chromosphere at the limb, seems to make unnecessary the assumption that the corona plays any part in the absorption. In this connection it would be interesting to determine whether the distance between the components of the 1474 line is constant over the entire surface of the Sun.

The problem of the solar rotation, so admirably investigated by

Crew and Dunér, gains new interest in the light of present knowledge. It is now possible to determine whether the lines employed in these two researches originate in different parts of the reversing layer, in which case it might become possible to harmonize the results. It can hardly be said that the ideas of Brester[1] on this point are sufficiently plausible to gain general acceptance.

It is impossible in a limited space to even touch upon the numerous applications of the new results to astrophysical problems. That the effect of pressure must receive attention in future investigations of the motions of stars and nebulæ in the line of sight cannot be doubted. The fact that narrow spectral lines are not always inconsistent with high pressures is of great importance in this connection. The close similarity of stellar spectra of Class II*a* with the solar spectrum indicates that the conditions of temperature and pressure in the atmospheres of these stars cannot differ widely from those existing in the Sun. The displacements due to pressure must therefore in such cases be in general too small to be detected with an ordinary spectrograph, and the measures of motion in the line of sight may be relied upon. In stars whose reversing layers are subject to higher pressures the displacements due to this cause may become appreciable. Fortunately, however, it has been shown that the wave-lengths of certain lines in the spectrum are apparently unaffected by pressure. These lines, if they can be found in the stars under investigation, may serve for the determination of motion in the line of sight. The pressures in the reversing layer might also be measured with other lines. It is evident, as Mr. Jewell has pointed out, that the vacuum tube should replace the spark or arc for this work. The form used by Professor Michelson, and described in a recent number of this JOURNAL,[2] is propably the best for the purpose. GEORGE E. HALE.

ON THE SPECTRUM OF CLÈVEITE GAS.

THROUGH a mistake in the types, it was made to appear that Professors Runge and Paschen's article in the last number of this JOURNAL had been published elsewhere. This, however, was not the case. The footnote on page 4 was intended to refer to previous papers by the same authors.

[1] *Théorie du Soleil.*

[2] *Ap. J.* **2**, 263, 1895.

HARVARD COLLEGE OBSERVATORY. CIRCULAR NO. 4.

A NEW STAR IN CENTAURUS.

A NEW star in the constellation Centaurus was found by Mrs. Fleming on December 12, 1895, from an examination of the Draper Memorial photographs. Its approximate position for 1900 is in R. A. 13^h $34^m.3$, Dec.—31° 8′. Attention was called to it from the peculiarity of the spectrum on Plate B 14151, taken at Arequipa on July 18, 1895, with the Bache Telescope, exposure 52^m. The spectrum resembles that of the nebula surrounding 30 Doradus, and also that of the star *A. G. C.* 20937, and is unlike that of an ordinary nebula or of the new stars in Auriga, Norma and Carina. This object is very near the nebula *N. G. C.* 5253, which it follows $1^s.28$, and is north 23″. No trace of it can be found on 55 plates taken from May 21, 1889, to June 14, 1895, inclusive. On July 8, 1895, it appeared on a chart plate, B 13965, and its magnitude was 7.2. On Plate B 10472 taken July 10, 1895, its magnitude was also 7.2. On December 16, 1895, a faint photographic image of it, magnitude 10.9, was obtained with the 11-inch Draper telescope, although it was very low, faint and near the Sun. On this date, and on December 19, it was also seen by Mr. O. C. Wendell with the 15-inch equatorial as a star of about the eleventh magnitude. An examination with a prism showed that the spectrum was monochromatic, and closely resembled that of the adjacent nebula. Although the spectrum is unlike those of the new stars in Auriga, Norma and Carina, yet this object is like them in other respects. All were very faint or invisible for several years preceding their first known appearance. They suddenly attained their full brightness and soon began to fade. Like the new stars in Cygnus, Auriga and Norma, this star appears to have changed into a gaseous nebula.

The star which was photographed in 1887 in the constellation Perseus apparently belongs to the same class. Its approximate position for 1900 was in R. A. 1^h $55^m.1$, Dec. + 56° 15′. Eight images of it were obtained on the Draper Memorial photographs in 1887, all in exactly the same place. Its photographic spectrum showed the hydrogen lines $H\beta$, $H\gamma$, $H\epsilon$, and a line near 4060, bright, and from this property it was discovered by Mrs. Fleming and assumed to be an ordinary variable star of long period. The spectrum is so faint that it is impossible to decide from it whether it should be regarded as a new star of the class of Nova Aurigae, or as a variable star of long period like *o* Ceti, as the hydrogen lines are bright in both these classes of objects.

The star soon faded away and does not appear on 81 photographs taken during the last eight years. It has also been repeatedly looked for in the sky without success. No trace of this star appears on two photographs taken November 3, 1885, and December 21, 1886.

A list of the new stars hitherto discovered is given in the annexed table. Some changes would occur in it, if changes were made in the definition assumed for this class of objects. Early observations of several objects frequently called new stars, but which may have been comets, and whose positions are uncertain, have not been included. The stars T Bootis and U Scorpii have not been included, although they also may be new stars, as only one appearance of each has been noted. The name of the constellation is followed by the right ascension and declination for 1900, and the greatest brightness. The year of appearance is followed by the name of the discoverer; or, in the case of the earlier stars, of the principal observer.

NEW STARS.

CONSTELLATION	R. A. 1900	DEC. 1900	MAG.	YEAR	DISCOVERER
	h m	° ′			
Cassiopeia	0 19.2	+63 36	—5?	1572	Tycho Brahé
Cygnus	20 14.1	+37 43	3	1600	Janson
Ophiuchus	17 24.6	—21 24	—4?	1604	Kepler
Vulpecula	19 43.5	+27 4	3	1670	Anthelm
Ophiuchus	16 53.9	—12 44	5	1848	Hind
Scorpius	16 11.1	—22 44	7	1860	Auwers
Corona Borealis	15 55.3	+26 12	2	1866	Birmingham
Cygnus	21 37.8	+42 23	3	1876	Schmidt
Andromeda	0 37.2	+40 43	7	1885	Hartwig
Perseus	1 55.1	+56 15	9	1887	Fleming
Auriga	5 25.6	+30 22	4	1891	Anderson
Norma	15 22.2	—50 14	7	1893	Fleming
Carina	11 3.9	—61 24	8	1895	Fleming
Centaurus	13 34.3	—31 8	7	1895	Fleming

THE NEW ALGOL VARIABLE IN DELPHINUS.

The variable star of the Algol type, *B. D.*+17° 4367, in the constellation Delphinus, announced in Circular No. 3, was again found to be faint by Professor Searle on December 17, 1895. From a discussion of the photographic and visual measurements so far made, it appears that its period is about $4^d\ 19^h\ 21^m.2$, and that it will again become fainter than the eleventh magnitude from $11^h.6$ to $15^h.8$, Greenwich Mean Time, on January 5, 1896.

EDWARD C. PICKERING.

December 20, 1895.

Recent Publications.

A list of the titles of recent publications on astrophysical and allied subjects will be printed in each number of The Astrophysical Journal. In order that these bibliographies may be as complete as possible, authors are requested to send copies of their papers to both Editors.

For convenience of reference, the titles are classified in thirteen sections.

1. The Sun.

Guillaume, J. Observations du Soleil faites à l'observatoire de Lyon, pendant le deuxième trimestre de 1895. C. R. **121**, 710–712, 1895.

Sartorio, G. W. Osservazioni solari eseguite nel Reale Osservatorio di Palermo. Mem. Spettr. Ital. **24**, 133, 1895.

Tacchini, P. Sulle protuberanze solari osservate al Regio Osservatorio del Collegio Romano nel 3° trimestre del 1895. Mem. Spettr. Ital. **24**, 131–132, 1895.

Tacchini, P. Sulle macchie e facole solari osservate nel 3° trimestre del 1895 al Regio Osservatorio del Collegio Romano. Mem. Spettr. Ital. **24**, 129–130, 1895.

Tacchini, P. Imagini spettroscopiche del bordo solare osservate a Catania e Roma nei mesi di maggio, giugno e luglio 1894. Mem. Spettr. Ital. **24**, Plate 318, Sept., 1895.

Tacchini, P. Imagini spettroscopiche del bordo solare osservate a Catania e Roma nei mesi di marzo, aprile e maggio 1894. Mem. Spettr. Ital. **24**, Plate 317, Sept., 1895.

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4. STELLAR SPECTRA, DISPLACEMENTS OF LINES AND MOTIONS IN THE LINE OF SIGHT.

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DESLANDRES, H. Recherches spectrales sur l'étoile Altaïr. Reconnaissance d'un mouvement orbital et d'une atmosphère. C. R. **121**, 629–632, 1895.

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5. PLANETS, SATELLITES AND THEIR SPECTRA.

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